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PROMOTING LOW-CARBON TRANSPORT IN INDIA

Transport Scenarios for India:
Harmonising Development and Climate Benefits

November 2015

UNEP DTU Partnership, Centre on Energy,
Climate and Sustainable Development Technical University of Denmark

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PROMOTING
LOW-CARBON TRANSPORT IN INDIA

Transport Scenarios for India: Harmonising Development and Climate Benefits

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November 2015

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LOW-CARBON TRANSPORT IN INDIA

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Abbreviations

- BAU Business-As-Usual
- BEV Battery Electric Vehicles
- Bn Billion
- Bpkm Billion passenger kilometers
- CAGR Compounded Annual Growth Rate
- CNG Compressed Natural Gas
- CCS Carbon Capture and Storage
- CO_2 Carbon dioxide
- CO_2e Carbon dioxide equivalent
- DFC Dedicated Freight Corridors
- E2W Electric 2-Wheelers
- E3W Electric 3-Wheelers
- E4W Electric 4-Wheelers
- EM Electric Motorcycles
- EV Electric Vehicles
- GDP Gross Domestic Product
- GHG Greenhouse Gases
- GoI Government of India
- Gt Giga tonne
- GWH Giga Watt Hours
- HSR High Speed Rail
- HSRC High Speed Rail Corporation of India Limited
- ICT Information and Communication Technology
- INDC Intended Nationally Determined Contribution
- ISMA Indian Sugar Mills Association
- JNNSM Jawaharlal Nehru National Solar Mission
- JnNURM Jawaharlal Nehru National Urban Renewal Mission
- LCMP Low-carbon Comprehensive Mobility Plans
- LCS Low Carbon Society
- LCT Low Carbon Transport
- MT Million Tonnes
- MER Market Exchange Rate
- MTOE Million tonnes Oil Equivalent
- NAPCC National Action Plan for Climate Change
- NBP National Biofuels Policy
- NEMMP National Electric Mobility Mission Plan
- NMT Non-motorized transport
- PHEV Plug-in Hybrid Electric Vehicles
- pkm Passenger Kilometers
- PT Public Transport
- tkm ton Kilometers
- UNFCCC United Nations Framework Convention on Climate Change
- USD US Dollars
- V2G Vehicle to Grid
- ZEV Zero Emission Vehicles

Executive Summary

The multiple transitions of income, population growth, industrial growth and urbanization witnessed in India have fuelled the need for travel and demand for commodities. Between 1970 and 2010, demand for passenger transport increased at a CAGR of 8.28 per cent, which was faster than economic growth, while the growth in freight transport equalled the rate of GDP growth. Road is the dominant means of transport, catering to 88 per cent of the demand for passenger transport and 60 per cent for freight.

Oil is the largest source of energy used for meeting up to 95 per cent of the total energy demand for the transport sector. India imports three-quarters of its oil demand, and therefore the growth of transport has implications for energy security. Transport is also a major contributor to greenhouse gas emissions, contributing 14 per cent of energy-related CO_2 emissions in 2010. In urban areas, growth in urban sprawl, incomes and vehicle ownership has resulted in a marked shift to personalized road-based modes, especially two-wheelers and cars. This is leading to significant negative externalities from congestion, rising air pollutant emissions, noise and consequent impacts on people's health and quality of life.

Recent national and subnational policies highlight India's commitment to meeting transportation demands while promoting development and minimizing environmental impacts. Following the Copenhagen Accord, India has endorsed the goal of limiting greenhouse gases to a target corresponding to 2°C temperature stabilization while following the national sustainable development goals. India's National Action Plan on Climate Change aims to cut emissions from the transport sector through policies that promote sustainability and energy efficiency. The recently announced INDCs (Intended Nationally Determined Contributions) envision developing safe, smart and sustainable green transport as key means of limiting greenhouse gas emissions in India.

This report's national-level assessment of low-carbon transport in India spans the time horizon through to 2050, and examines two alternative scenarios: a business-as-usual development scenario, and an alternative scenario where actions follow the sustainability approach. The analysis of future scenarios for the transport sector is conducted using an economy-wide energy system model: ANSWER MARKAL. The alternative scenarios explore a range of interventions across demand and supply systems following the 'avoid-shift-improve' paradigm.

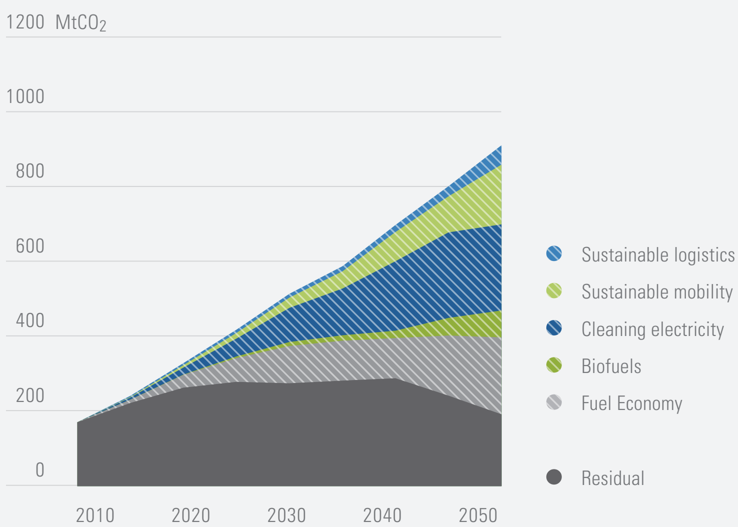
The scenarios assessment shows that a sustainable low-carbon transition for transport in India is feasible and would significantly reduce greenhouse gas emissions while contributing to multiple sustainability co-benefits.

Key findings

1. The reduction in CO_2 emissions would occur through a broad portfolio of options (Fig A). The five key wedges that deliver mitigation benefits in the sustainable low-carbon scenario that are consistent with the global 2°C target are: electricity cleaning, fuel economy, sustainable mobility, biofuels and sustainable logistics, listed in the order of their contribution towards mitigation. The carbon price in the sustainable low-carbon scenario facilitates a higher share of renewables, natural gas and coal with CCS (carbon capture and storage), resulting in a reduction of the CO_2

content of electricity from 0.80 kg CO_2 per KWH of electricity in 2010 to 0.06 kg CO_2 per KWH of electricity in 2050. The implementation of stringent fuel economy targets, consistent with the vision set under the Global Fuel Economy Initiative for cars and two-wheelers, is the second largest wedge. The third significant mitigation wedge is sustainable mobility, which spans a range of initiatives for passenger transport including faster implementation of metros and BRT systems and their better integration with non-motorized transport modes and feeder buses, and a higher share of rail in intercity transport. Biofuel penetration, which is enhanced through support from national policies and enabling mechanisms, and the carbon price constitute the fourth wedge. The fifth wedge comes from interventions in the freight transport sector, which involves implementation of dedicated freight corridors, demand reduction for coal freight, etc.

Figure A. CO_2 Mitigation wedges from transport



Source : Dhar & Shukla, 2015

2. The demand for cars and two-wheelers will register increases; however, the increase in ownership of cars will be more profound. The future would also envision a levelling out of difference in vehicle ownership between urban and rural areas.
3. Increasing investments in rail for passenger transport, both intercity and intra-city, can help in reducing CO_2 emissions in the long term and also in improving energy security and reducing emissions of air pollutants.
4. Dedicated freight corridors would contribute towards low-carbon goals, and also be a critical driver of a balanced regional development and increase in the share of rail in freight transport.
5. Fuel efficiency improvements, which are in line with the vision of Global Fuel Economy Initiative, would contribute to the improvement of energy security and reduction of air pollutants.
6. India has significant potential for biofuels using crop waste, which would be required to meet the blending target of 20 per cent; however, investments in R&D and pilot projects would be essential.
7. Electric vehicles would significantly reduce air pollution; however, the reduction in CO_2 emissions would depend on cleaning the electricity.

8. Electric cars will require strong policy support relative to electric two-wheelers, which will gain commercial success early. Electric two-wheelers with limited driving range would gain success within cities due to short trip lengths; however, more expensive vehicles with a longer driving range would require domestic R&D and technology transfer to drive down the costs.

Major Policy Recommendations

Improving the penetration of alternate fuels and vehicles

Improving the penetration of electric vehicles would require: clear policy signals to stimulate domestic manufacturing; setting standards and regulations for charging infrastructures (devices and batteries); incentives for vehicles; investment into grids and efficient pricing of electricity.

Greater penetration for biofuels can be facilitated through a stable policy framework, investment in biofuel collection and transportation infrastructure, and enabling public private partnership. Since meeting 20 per cent blending targets would need the second generation pathway, adequate investments should be put into R&D and pilot projects for technology demonstrations.

Urban low-carbon transport

Essential to sustainable transport are urban planning strategies that promote compact and mixed land-use development, integration of land-use and transportation, and facilitate a shift to public transport. National governments can help in developing guidance and codes for the same.

Local governments can provide incentives for cleaner technologies, e.g. the use of EVs can be encouraged by a range of interventions, including mandates and incentives that promote investments in charging infrastructure, developing local EV targets, stricter emission standards for vehicles, priority in parking and traffic for EVs, and facilitating public private partnerships.

Promoting public transport and NMT in cities

Public transport and NMT reinforce each other, and greater adoption of both can lower travel demand. Thus investments in public transport, including mass transit and NMT, should be prioritized from national funds.

If complemented with public transport infrastructure, NMT infrastructure improvements in cities can make a substantial contribution to improving access to all socio-economic groups for public transport and consequently ridership. NMT infrastructure and policies therefore should be an important part of local area plans and urban development plans. Increasing pedestrian and cyclists' right-of-way should be an important consideration in road widening and planning projects in cities.

Increasing the share of rail in intercity passenger transport

Improving rail infrastructures, especially building HSR (high speed rail), is capital-intensive and therefore it is important to look at innovative funding that facilitates private sector participation through market-friendly policies. Since infrastructure is a long-term asset that delivers sustained benefits over time, financial instruments with longer-maturity would be required. HSR investments can deliver many co-benefits, and therefore need to be viewed comprehensively for the long-term development benefits they generate; thus discount rates should be used accordingly.

State and local government support would also be needed for building the complementary infrastructure necessary for intercity rails, e.g. building connecting links with important transport nodes like airports, bus stands, railway stations, etc.

Sustainable logistics

Rail is considered more efficient than road transport, and government is prioritizing DFCs (dedicated freight corridors), which deliver energy efficient and environmentally cleaner freight. Two DFCs are being constructed in the first phase of implementation: the Western Dedicated Freight Corridor (1,520 km), and the Eastern Dedicated Freight Corridor (1,856 km). DFCs can help reduce CO_2 emissions, especially when the electricity is also decarbonized.

Besides rail, costal shipping and inland water transport are efficient transport modes. However, an important task is to develop a comprehensive freight transport plan and create supporting trunk infrastructure with allied investments.

Creating a domestic low-carbon transport industry in India

India is evolving as a very large market for low-carbon businesses. The scenarios assessment shows that transport systems, related infrastructures and vehicles offer sizable market opportunities for domestic manufacturers to become global players within the coming decades. Early policy signals and targets are vital to prompt innovations and investments that can stimulate the domestic market in areas such as EVs and allied industries such as battery technologies, the manufacture of rail wagons, and Generation II and IV biofuel production using feed-stocks that do not compete for land otherwise suitable for food production.

Leveraging global climate finance

Transport infrastructures need substantial upfront investments that offer investors long-term benefits, though their external co-benefits are immediate and substantial. National and city governments can leverage climate finance instruments to fast-track the implementation of these projects. There exists significant potential for developing bankable projects through CDM funds, NAMAs and Green Climate Fund for low-carbon mass transit projects, new vehicle technologies, and climate-resilient transport infrastructures.

Sustainable low carbon transport is an essential enabler of green growth at the national level by developing domestic manufacturing and generating green jobs. This report makes a strong case to speed up the implementation of sustainable low-carbon transport to meet the global mitigation target, but more importantly to reap early co-benefits in the form of improved air quality, energy security, and reduced congestion, all of which are essential to a balanced sustainable development for India.

Harmonizing sustainable development and low-carbon transport actions

The analysis in this report shows that the future evolution of India's transport system can harmonize the twin goals of global policymaking – achieving sustainable development and mitigating climate change, and that one is not at the expense of other.

Cities are a good example of this harmonization where the benefits of sustainable low-carbon transport accrue sizably and in the near-term. In the case of India, the transition from a low to high-level of urbanization, which will continue throughout the coming decades, will remain through the century. The demand on India's transport system thus will steadily increase through the century, offering opportunities to transform vehicle and infrastructure stocks to create more inclusive, environmentally sustainable and low-carbon transport systems.

Photo Credit: Ekabhishek

1 Introduction

1.1 Background

India is currently the fourth-largest emitter of greenhouse gases (GHG) globally. The transport sector accounts for 13 per cent of India's energy-related CO_2 emissions (MOEF, 2010), and, as such, opportunities exist to mitigate GHG emissions and make India's transport growth more sustainable and climate compatible by aligning the objectives of development and climate change. India's National Action Plan for Climate Change (NAPCC) recognizes that GHG emissions from transport can be reduced by adopting a sustainability approach through a combination of measures, such as increased use of public transport, higher penetration of biofuels, and enhanced energy efficiency of transport vehicles (GoI, 2008).

This document is produced as part of a larger research project on 'Promoting Low-Carbon Transport in India', an initiative of the United Nations Environment Programme (UNEP), hereafter referred to as the Low-Carbon Transport (LCT) project. The key objectives of the LCT project are as follows:

a) Delineating an enabling environment for coordinating policies at the national level to achieve a sustainable transport system

b) Enhancing the capacity of cities to improve mobility with lower CO_2 emissions. The LCT project has been endorsed by the Ministry of Environment and Forests (MoEF), Government of India, and is jointly implemented by the UNEP DTU Partnership, Denmark (UDP); Indian Institute of Technology, Delhi (IIT-D); Indian Institute of Management, Ahmedabad (IIMA); and CEPT University, Ahmedabad.

1.2 Context

The transport sector can play a crucial role for the mitigation of global greenhouse gas emissions (IPCC, 2007). Globally, transport accounted for a fifth of total energy consumption, and had a share of 23 per cent of total CO_2 emissions in 2012 (IEA, 2014a). In the future, an increasing share of energy demand and CO_2 emissions is expected to come from the transport sector, the majority of which from developing countries, especially China and India, where the economic growth and corresponding increase in per capita incomes is leading to an increase in demand for mobility and rapid motorization. At the same time, 98 per cent of all energy demand for transport comes from fossil fuels, and the dependence on fossil fuel will continue to remain high under the business as usual (BAU) scenario (ibid). This dependence on fossil fuels, besides having implications for climate change, also presents a significant challenge for the energy security and trade balance of countries like India, which meets three-fourths of its domestic oil needs through imports. Another consequence of fossil fuel use in transport has been the impact on urban air quality in Indian cities (Kathuria, 2002; Guttikunda & Jawahar, 2012) and human health (Dholakia, Purohit, Rao, & Garg, 2013). Cities in the developing countries of Asia have low per capita greenhouse gas emissions (Kenworthy & Laube, 1999) compared to the cities of high income developed countries. Growth of freight transport has been increasing at a rapid pace, and economic growth is expected to spur future demand for freight transportation of commodities moved by road, rail, water, pipelines, and air freight carriers. The choices for freight transport infrastructure will significantly influence energy demand and CO_2 emissions.

The transport sector therefore presents multiple challenges, and demands a coherent approach to transition from the current unsustainable trajectory. A possible approach is to adopt a sustainable development paradigm (Shukla, Dhar, & Mahapatra, 2008), which can facilitate transitioning to a low-carbon future while simultaneously providing many development dividends. Specifically, in the case of the transport sector, this would be possible through appropriate technology selection for vehicles, infrastructure choices, urban planning, demand substitution and changes in travel behaviour.

India's National Action Plan for Climate Change (NAPCC) recognizes that GHG emissions from transport can be reduced by adopting a sustainability approach through a combination of measures, such as an increased share of public transport, higher penetration of biofuels, and enhanced energy efficiency of transport vehicles (GoI, 2008). Recently, India's planned actions on climate change, also referred to as Intended Nationally Determined Contributions (INDC), highlights sustainable and green transport as a key focus area for GHG mitigation (UNFCCC 2015). Several other subnational policies and initiatives (outlined later in this chapter) are aimed at meeting freight and passenger transport demand while delivering environment and development benefits.

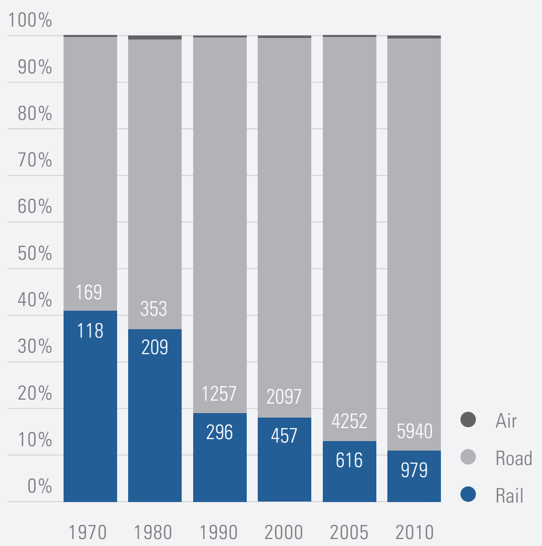
1.3 Trends in urbanization

According to the Census of India 2011, there are 7,935 urban centres in India, of which 4,041 are statutory towns, meaning settlements with urban governments. Between 2001 and 2011, the population living in Class-I cities, i.e. cities with a population over 100,000, has increased from 62 to 70 per cent. The number of million-plus cities has increased from 37 to 53 during the same period and concurrently, the population living in these cities has increased from 26 to 43 per cent. These trends point to the fact that higher growth has been witnessed in larger cities compared to smaller cities in the last decade. The faster growing cities have experienced economic growth and attracted people from rural areas.

The form of India's urban centres differs from those in developed countries due to their traditionally dense and mixed land use structure. These Indian cities do not follow a simple structure of a central core followed by suburban development, but have developed into multi-nuclei structures with organically evolved road network patterns (Mahadevia, Joshi and Datey, 2013). In most Indian non-metro cities, the average trip lengths are less than 5km. Thus, historically, while the urban form was sustainable, it is now changing into a low density, spread out form of development (ibid). In the absence of good public transport, this has resulted in a mobility pattern with longer trip lengths catered to mainly by private transport. This growth has also demanded significant infrastructure investments in roads and public transport. Over two dozen cities in India have planned mass transit systems.

The urban form of cities, including these transport infrastructures, will be defining features for mobility and emissions. Infrastructure investments directly influence travel behaviour patterns, and have an indirect effect through the energy embedded in materials and construction. Since a large part of this infrastructure stock is yet to be built, urban development plans offer huge scope for intervention to make the transition to sustainable low-carbon cities and avoid being locked into carbon-intensive infrastructure pathways.

Figure 1. Trend in passenger transport demand (billion pkm)



Sources: Data for Rail: Ministry of Railways, Road: Ministry of Road Transport and Highways, Air: Ministry of Civil Aviation.

1.4 *Trends in transport demands*

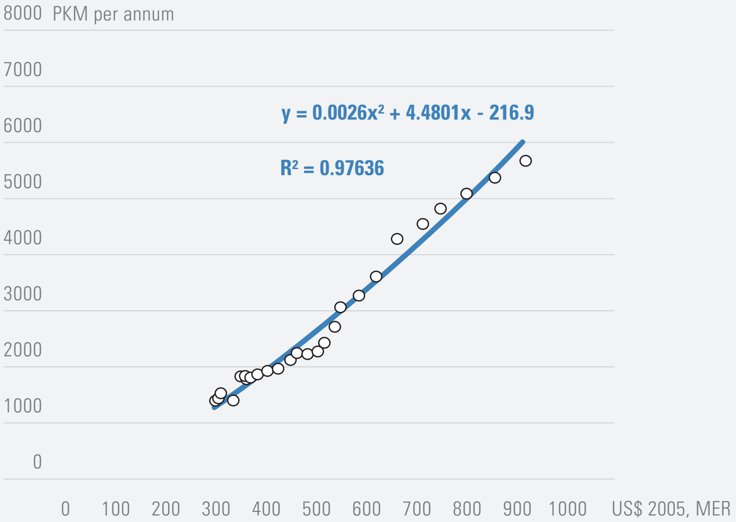
Trends in passenger transport

Passenger transport demand has increased from 289 billion pkm (passenger-kilometres) in 1970 to 6,966 billion pkm in 2010 at a CAGR of 8.28 per cent (Dhar & Shukla, 2015), which has been faster than economic growth. A large part of this demand was from road transport, which accounted for 88 per cent (Figure 1). Indian Railways is the largest railway network in Asia, with a daily ridership of nearly 23 million passenger-kilometres (GoI, 2012). Despite a growth in network and passenger traffic, Indian Railways suffer from huge capacity constraints and inadequate infrastructure. The result of this has been that rail has steadily lost share of passenger transport and accounted for only 11 per cent of demand in 2010 (Figure 1). Air traffic has grown fastest amongst rail, road and air in the last decade; however, the overall share of air is still less than 1 per cent (Dhar & Shukla, 2015). The high growth of road transport occurred both for intercity transport (including transport from rural areas to cities) and within the cities.

The preference for road transport reflects a preference for faster modes of transportation given that people like to spend a limited time travelling (Schafer & Victor, 2000; Zahavi, 1981). Buses and personal modes of transport like cars and two-wheelers provide point-to-point connectivity and have shorter waiting times, and are therefore preferred over rail. The share of cars in intercity road transport has increased due to higher incomes and improvements of selected highways in the country. The per capita mobility in India for motorized transport has shown a strong correlation with an increase in income (Figure 2) and is in line with experience from across the world (Schafer & Victor, 2000).

India has witnessed a rapid increase in vehicle ownership. Between 2001 and 2011, the percentage of households owning two-wheelers increased two-and-a-half times in urban and rural

Figure 2. Correlation of motorised per capita mobility with per capita GDP using data from 1980 to 2010



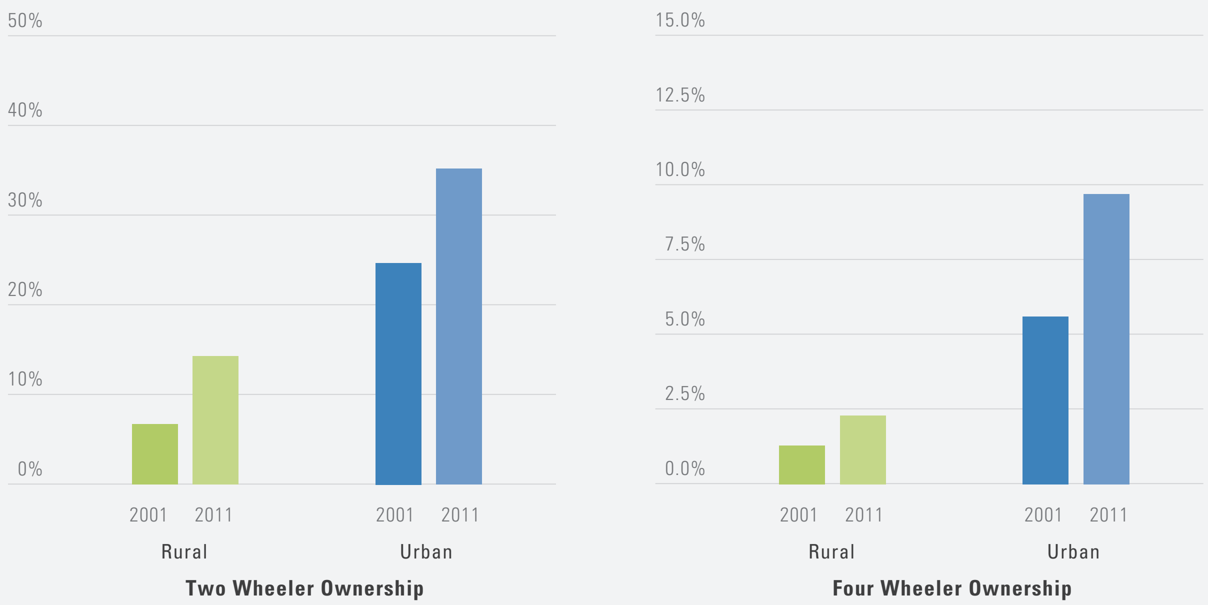
Source: Dhar & Shukla, 2015

areas. The increase was higher in the case of four-wheeler ownership (Figure 3). Despite these trends, the current level of vehicle ownership in India is low and has ample scope for growth. At 15 cars per thousand persons, India's car ownership is amongst the lowest in the world. India's two-wheeler ownership of 82 vehicles per thousand people is much higher.

Trends in freight transport

Road and rail are two major modes for freight transport. Rail freight increased from 127 billion tkm in 1970 to 626 billion tkm in 2010 at a CAGR of 4.06 per cent, whereas road freight increased from 67 billlion tkm to 1,128 billion tkm during the same period at a CAGR of 7.3% (Dhar & Shuka, 2015). The overall growth in demand for freight has nearly equalled GDP growth. Between 1980 and 2000, there was a significant shift in the share of freight transport

Figure 3. Trends in Vehicle Ownership

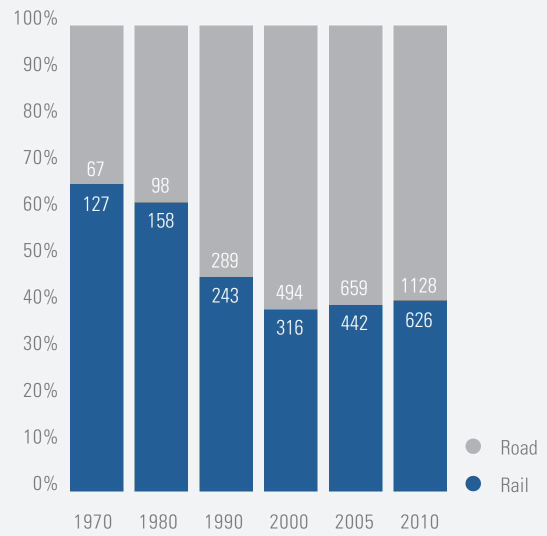


Source: Census of India, 2011

from rail to road; however, since 2000, the share of rail has remained at around 40 per cent (Figure 4).

In addition to road and rail, freight transport includes a small share from coastal shipping, barges on inland water ways, and pipelines. The limited availability of perennial water has restricted the growth of inland waterways; however, pipelines and coastal shipping have recorded a steady growth. The growth in capacity (gross tonnage) of coastal shipping has, however, been slower than both rail and road (Dhar & Shukla, 2015). In 2010, 108 billion tkm of freight was taken by coastal shipping, which accounted for less than 6 per cent of overall demand (Dhar & Shukla, 2015). The amount of petroleum products and natural gas transported in 2010 was around 116 billion tkm (Dhar & Shukla, 2015)

Figure 4. Trend in freight transport demand (billion tkm)



Sources: Data for Rail: Ministry of Railways, Road: Ministry of Road Transport and Highways, Air: Ministry of Civil Aviation.

1.5 Transport and energy consumption

The share of the transport sector in the total primary energy consumption of India was around 9.4 per cent in 2012, and 95 per cent of the energy demand from the sector was met by oil (IEA, 2014a). The transport sector is also the largest final demand for oil. India imports more than three-fourths of its oil demand, and was the fourth-largest importer of crude oil and petroleum products in the world in 2013 (BP, 2015). The transport sector is the largest commodity importer, and therefore has a significant effect on the macro economic situation of the country. Future energy transitions in the transport sector will therefore have a profound effect on the energy security of India.

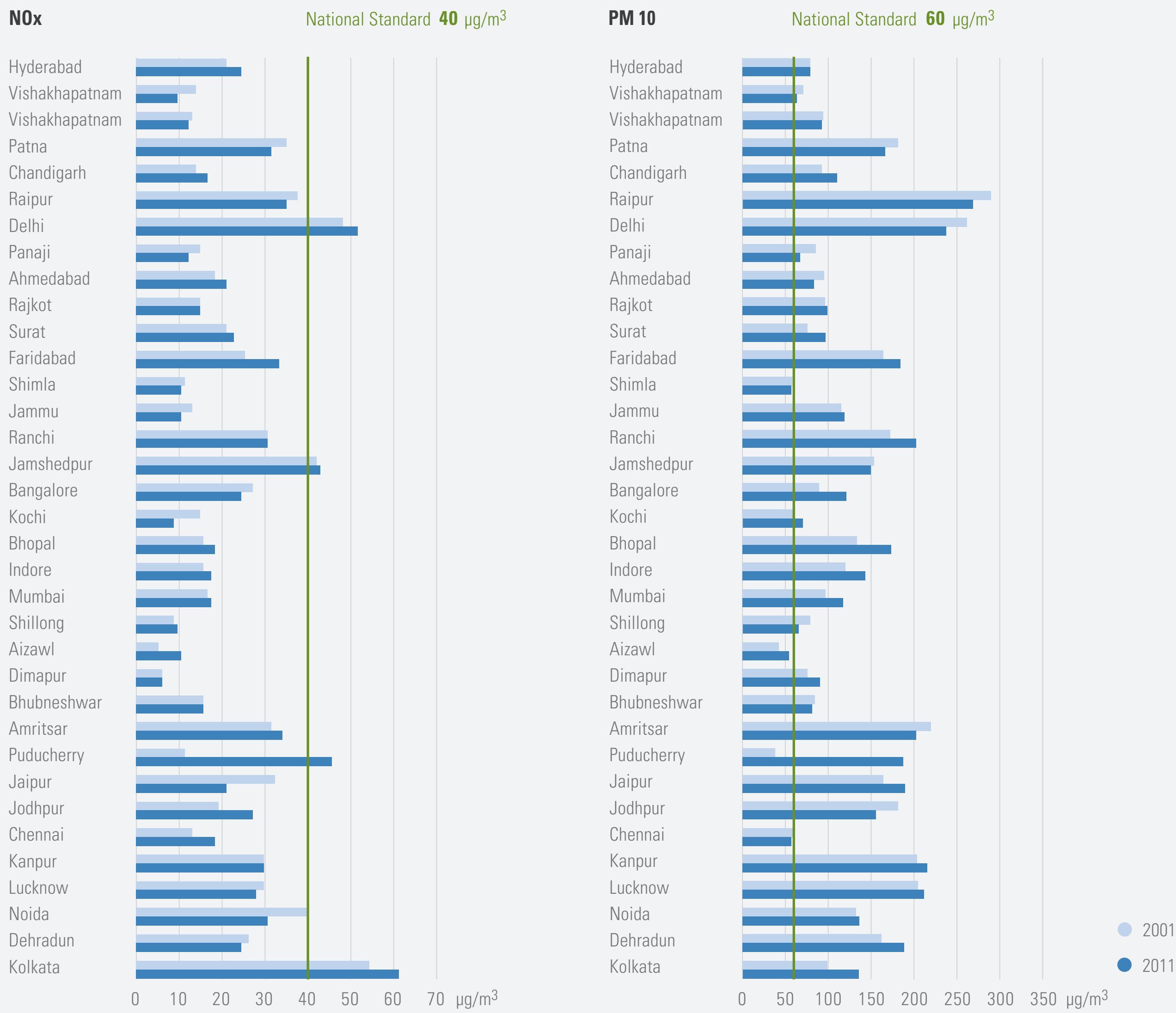
Petrol and diesel are the two principal fuels used for transportation. Diesel demand has grown faster than petrol in the last decade (PPAC, 2012) due to government policies that deregulated petrol prices and limited increases in diesel prices.

1.6 Transport and the environment

An increase in motorization is leading to externalities, including rising greenhouse gas emissions, local air pollution, congestion and noise. Between 1985 and 2005, CO_2 emissions from road transport in India grew at an average rate of 5.7 per cent (Garg, Shukla, & Kapshe, 2006). The transport sector is increasingly becoming a major contributor to deteriorating air quality in cities (Guttikunda & Jawahar, 2012). India has the unfortunate distinction of having a large number of cities recording high levels of air pollution. The four most polluted cities globally, based on PM2.5 levels, were Indian (Delhi, Patna, Gwalior and Raipur), and 33 per cent of the top 100 polluted cities were also from India (WHO, 2014). High levels of PM2.5 and NOx lead to increasing morbidity (Guttikunda and Jawahar, 2012). Over time, there is an observable trend shift as levels of PM10 and NOx are increasing in a number of cities (Shukla, Garg, & Dholakia, 2015). In an assessment by the Central Pollution Control Board of 164 cities, over 75 per cent were found to have high or critical levels of PM10 (CPCB, 2014), while more than half of the 164 cities had moderate to critical levels of NOx. Figure 5 shows the annual mean levels of PM10 and NOx in 35 Indian cities, and it can be observed that PM10, a key criteria pollutant, is way beyond the national standard in most of these cities.

In India's cities, growing motorized transport is leading to significant environmental impacts from congestion and rising air pollutant emissions, affecting human health and quality of life.

Figure 5. NOx and PM10 levels in major Indian cities



Source: CPCB (2014)

1.7 Transport policies and investments in India

India is a geographically diverse and vast country. National transport policies are developed based on the diversity of transport demand, the range of fuel supply options, the mix of modes and vehicle technologies, and corresponding infrastructures. The transport system characteristics vary at the national and subnational levels, and so do the policy interventions. Transport decisions interface with numerous other development policy domains, e.g. land-use, energy, environment, technologies and finance. The transport decisions have inherent long-term lock-ins lasting several decades.

The transport policy landscape in India has evolved extensively with the implementation of several national and subnational transport policies with the objective of enhancing passenger mobility, improving logistics of freight transport, improving efficiency, promoting penetration of cleaner fuels and vehicles, and reducing air pollution and congestion (Table 1). Similarly, Indian cities have successfully implemented mass transit systems, upgraded public transport, improved infrastructure for non-motorized transport, and integrated sustainable transport measures into urban plans.

The transport sector makes up 45 per cent of the total infrastructure investments in India.

Table 1: Overview of transport policies in India

Sector	Policy/ Plan	Highlights
Urban Transport	National Urban Transport Policy	• Enhancing mobility to support economic growth and development • Reduce environmental impacts • Enhancing regulatory and enforcement mechanisms
	National Mission on Sustainable Habitat	• Sub-mission under India's National Plan on Climate Change • Enhancing public transport is one of the key focus areas
	Smart City and AMRUT Programs	• To develop 100 smart cities • Rejuvenating and revitalizing 500 cities
Alternate Fuels and Vehicles	National Policy on Biofuels	• Proposed blending target of 20% blending of biofuels, both for bio-diesel and bio-ethanol by 2017 • Financial incentives • Waiver on excise duty for bio-ethanol and Excise duty concessions for biodiesel
	National Electric Mobility Mission Plan	• Investments in R&D, power and electric vehicle infrastructure • Savings from the decrease in liquid fossil fuel consumption • Substantial lowering of vehicular emissions and decrease in CO_2 emissions by 1.3%-1.5% compared to BAU in 2020 • Phase-wise strategy for Research and Development, demand and supply incentives, manufacturing and infrastructure upgrade
Intercity Passenger Transport	High Speed Rail Project	• To develop High Speed Rail corridors in India • 2000 km High Speed Railways Network (HSR) by 2020
	National Highway Devlopment Project	• To meet the need for the provision and maintenance of National Highways network to global standards • Improving more than 49,260 km of arterial routes of NH Network promote economic wellbeing and quality of life of the people
Efficiency	Fuel Economy Standards for cars	• Binding fuel economy standards starting 2017 • Fuel Efficiency improvement in cars by 10% in 2017 • 20% in 2022 relative to 2010 levels
	Auto Fuel Policy	• Phased implementation of Vehicle and Fuel Quality norms in the country
Freight	Dedicated freight corridors	• Double employment potential in five years (14.8% CAGR) • Triple industrial output in five years (24.57% CAGR) • Quadruple exports from the region in five years (31.95% CAGR)

Source: Adapted from Shukla and Pathak (forthcoming)

Transport sector investments amounted to 2.6 per cent of GDP between 2006 and 2011. There are plans to increase investments to 3.6 per cent of total GDP in the period between 2018 and 2022 (GoI, 2012a) for the expansion and modernization of transport infrastructure, e.g., in expanding and upgrading roads and highways, reducing congestion in railways, the electrification of rail corridors, investments in dedicated freight corridors, expansion of air infrastructure, investments in high speed rail and mass transit in cities. Improving coastal shipping and inland water-based transport is now receiving some attention, and this has been mentioned as one of the focus areas in the National Urban Transport Policy and India's INDC. Planned initiatives include improving the infrastructure and capacity of waterways by creating an integrated 'Waterways Transportation Grid'. This will facilitate connections between national waterways with road, rail and ports. Policies for alternate fuels, such as the National Electric Mobility Mission Plan (NEMMP) and the National Biofuels Policy (NBP) (MNRE, 2009) are aimed at increasing penetration of low-carbon fuels and technologies in the country. The Auto Fuel Policy (GoI, 2014a) lays down the vision and roadmap for advancing fuel quality and vehicle emission norms in the country.

Emerging policies in the transport sector have focused on achieving multiple objectives in meeting the transport demand while addressing developmental and environmental objectives (Table 1).

1.8 *India's climate change strategy*

India's transport sector accounted for around 14 per cent of energy-related CO_2e emissions in 2007 (MoEF, 2010), and future scenarios project an increasing share of CO_2 emissions from transport (Shukla et al., 2015a; Dhar & Shukla, 2015).

The Government of India recognizes the urgent need to look at sustainable mobility solutions to reduce dependency on imported energy sources, reduce GHG emissions, and mitigate the adverse effects of transportation. In order to mitigate these, a portfolio of interventions have been planned, which includes fuel efficiency improvements, improving inspection and certification systems for reducing emissions from on-road vehicles, urban planning to reduce travel demand, improving mass transport, shifting to alternate fuels and technologies including biofuels and electric vehicles, and improving the overall system efficiency of infrastructure.

India has shown willingness to contribute to the global efforts of meeting the challenge of climate change. India is a signatory to the Copenhagen Accord, and has endorsed the goal of limiting greenhouse gases to a target corresponding to 2°C temperature stabilization while following a sustainable path. The Indian government, as a part of its National Action Plan on Climate Change, has decided to cut emissions from the transport sector through policies that promote sustainability and energy efficiency (GoI, 2008). A key focus area for mitigation in India's INDC submitted to UNFCCC in October 2015 is to develop a safe, smart and sustainable green transport network (UNFCCC, 2015).

Recent national and subnational policies highlight India's commitment to meeting transportation demands while promoting development and minimizing environmental impacts. Key focus areas include fuel and emission norms, urban mass transit, high speed rail corridors, dedicated freight corridors and an increasing share of alternate fuels and vehicle technologies.

Low-carbon transport strategies are now finding a prominent place in India's recent climate plans.

1.9 Research questions and chapter outline

This report addresses the following questions:

- What are the demand transitions within the transport sector for passenger and freight transport?
- How do these transitions change if the development follows a more sustainable pathway?
- How can the transport sector contribute to the goal of limiting global warming to 2°C?
- What are the co-benefits of actions for transport in a low-carbon world?

The report attempts to delve into the transport landscape of India, and spans demand sectors (passenger and freight) supply fuels, technologies and policy implications. The report is divided into 10 chapters. Following the introduction chapter, the next chapter describes the scenario framework, socio-economic transitions and assessment methodology. The third chapter describes the framework and estimation methodology. Chapters Four and Five discuss the scenarios and mitigation options for the passenger and freight sectors respectively. The following four chapters discuss in detail the storylines and results of vehicle fuel economy policies, electric vehicles, biofuels and decarbonization of electricity. Each of these sections shows quantified CO_2 emission reductions in alternate scenarios, and highlights their co-benefits. The final chapter lays down the future roadmap for sustainable low-carbon transition for India. The report will focus on land transport modes, and it is only to the extent that land transport faces competition from shipping, air, and pipelines that these other modes will be discussed.

Photo Credit: Dmitry A. Mottl

2 Scenarios, Socio-Economic Drivers and Assessment Methods

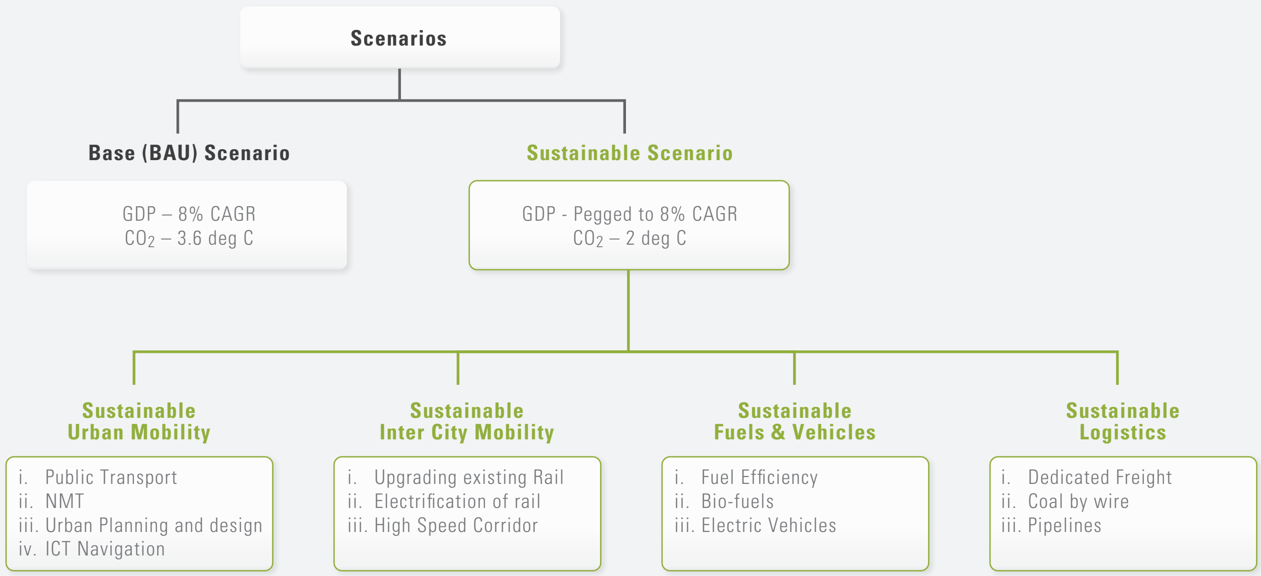
2.1 *Scenario architecture*

This assessment considers two scenarios, each representing the future transportation transition for India and spanning the time horizon to 2050 (Figure 6). The scenario constructs vary by the underlying development perspectives.

The business-as-usual scenario, referred to as BAU henceforth, assumes future economic development along the conventional pathway without any GHG mitigation commitments. The scenario assumes that a continuation of existing trends and socio-economic development would mimic the resource-intensive development path followed by developed countries. Energy intensity improvements happen; however, these too follow the existing dynamics.

The sustainable scenario is based on two key principles: i) a strong emphasis on sustainable development objectives; and ii) a mix of mitigation actions that are aligned via a common global carbon price trajectory to ensure cost-effective global mitigation actions deliver the 2°C climate stabilization target. The sustainable scenario encompasses a number of strategies on the demand side and supply side (Figure 6). The demand side strategies are akin to the avoid/shift strategies (Sims et al., 2014), and can be taken for passenger transportation within cities (or urban mobility) or intercity transport as well as freight (logistics). The supply side strategies improve the vehicles or change the fuels. These strategies are explored individually without any carbon price, and also collectively.

Figure 6. Scenario Storylines



2.2 Scenario drivers

Economy

GDP

Estimations vary on India's future GDP growth (Figure 7). However, various projections are in agreement that the Indian economy will be one of the fastest growing economies in the future (OECD, 2012; IEA, 2012; EIA, 2013). The Indian government projects high growth rates of 8 and 9 per cent for planning purposes (NTDPC, 2014; GoI, 2006). The 8 per cent GDP growth scenario is the closest to the current dynamics at the global, regional and local level, and is therefore designated as the base scenario around which the sustainable scenarios are analysed. The GDP would grow more than 15 times between 2010 and 2050 at a CAGR of 7.1 per cent.

Structure of the economy

The structure of the economy essentially follows the definition (Appendix, Table B) provided by the Central Statistical Organization of India (CSO, 1989).

There has been an increase in the commercial and industrial share of GDP at the expense of agriculture in the past four decades (Figure 8). The share of transport has however recorded a slow increase. India is thus transitioning from a rural, farm-based economy to a more modern and industrialized nation. The future GDP shares have been estimated using the logistic regression (equation 1) keeping in mind the past transitions and a future state where India has fully transformed into a modern and developed economy.

Figure 7. GDP Growth Rate Future

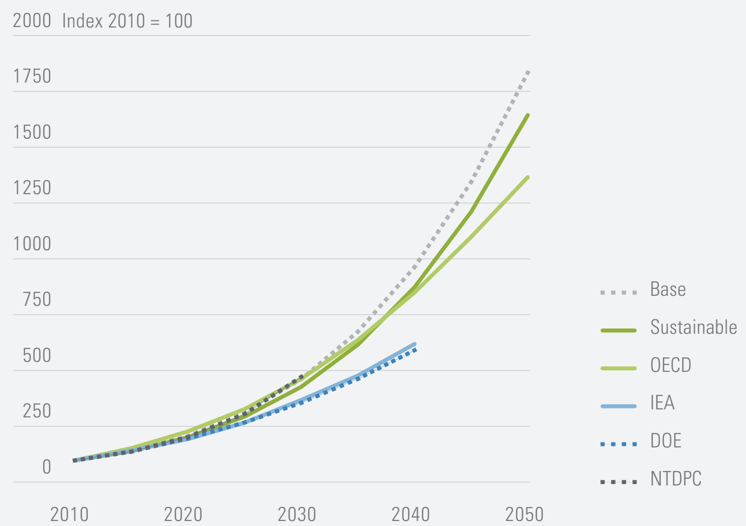
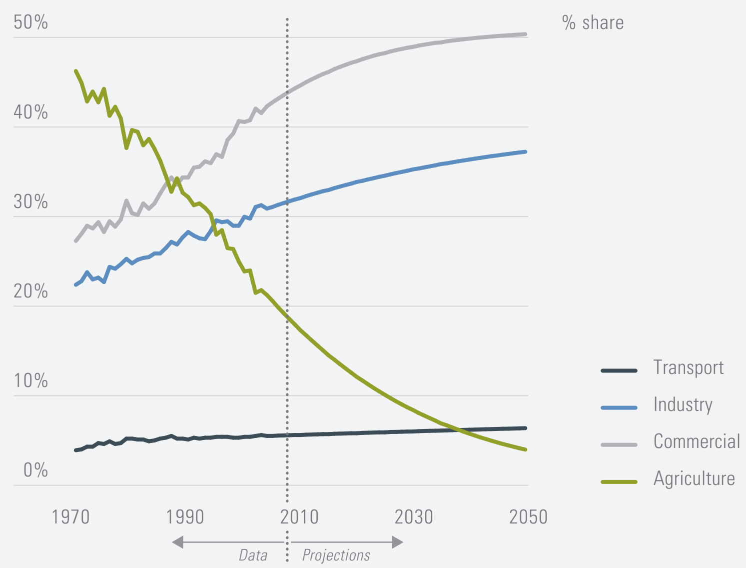


Figure 8. Structure of Economy



$$Share_{ij} = A\frac{\exp{(a+bt)}}{1+\exp{(a+bt)}}$$ Equation 1

$Share_{ij}$ = Share of sector i (industry, commercial transport and agriculture) at time j

A = Asymptotic value

a, b = Coefficients which are estimated using historical trends

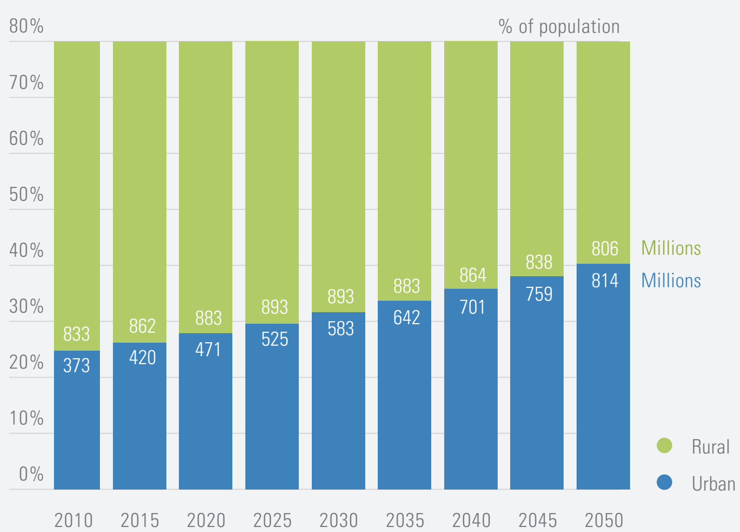
t = time

The asymptotic value for the industrial sector was set at 40 per cent based on a review of industrialized economies. The asymptotic value for the commercial sector was set at 51 per cent, and 8.5 per cent was considered accurate for the transport sector. The increase in all other sectors is at the expense of agriculture, where achieving even a 4 per cent CAGR over the long term is challenging (Planning Commission, 2007; Panagariya, 2007).

Demographics

Despite the decline in the total fertility rate in India, the population will continue to grow in the coming decades. Based on the medium variant projections from the UN Populations division, India's population will grow at a compounded average growth rate of 1.0 per cent between 2010 and 2030, resulting in a population of 1.47 billion. Post 2030, the population growth rate will decline to a much slower rate of 0.5 per cent between reaching 1.62 billion in 2050.

Figure 9. Rural urban population transitions



Source: UN, 2014

Urbanization

India's urbanization, at 33 per cent of the population, is much lower than in developed countries. This is projected to grow through 2050; however, the rate will slow down after 2030. Between 2014 and 2050, urban areas will add four hundred million people, taking the share of urban population to 52 per cent (Figure 9). In terms of urban population, India will be the second most populous country after China (UN, 2012). A large part of this growth will happen in million-plus cities, and by 2030 India will have seven megacities with populations over 10 million (UN, 2014). The growth in the number and size of cities accompanied by increasing per capita incomes are expected to drive vehicle ownership and urban demand for freight and passenger transport. Similarly, the expansion of cities will increase distances between work, home and other travel destinations, resulting in longer trips (Pathak & Shukla, 2015). The form and pattern of urbanization hence will have significant influence on future energy use and emissions (Pathak et al., 2015).

Household size

Household size has reduced in both rural and urban areas; however, the trend is more evident in urban areas due to the growing nuclearization of families (Census of India, 2001). The trend has been extrapolated (Table 2) by considering an asymptotic value of 2.5 per household. The asymptotic value is based on the average household sizes in developed countries.

Social transitions

Income transitions

Per capita incomes are expected to increase from US$1158 in 2010 to more than US$15,000 by 2050 based on population and GDP projections for BAU. This profound income transition is expected to result in a higher ownership of personal vehicles (Dargay, Gately, & Sommer,

2007) (Figure 10) and higher demand for mobility (Schafer & Victor, 2000).

The ownership of vehicles has increased rapidly in the last decade (Appendix, Table A) both rural and urban areas. The ownership of two-wheelers is going to increase further; however, more profound will be the changes in the ownership of cars, which are expected to increase from 30 per 1,000 persons in 2010 to 183 in 2050 for urban areas and from 7 to 166 during the same period for rural areas (Figure 10).

Table 2: Trends in Household Size

Year	Average Size of Household	
	Rural	Urban
2000*	5.40	5.10
2005	5.23	4.80
2010	5.06	4.52
2015	4.90	4.25
2020	4.75	4.00
2025	4.60	3.76
2030	4.45	3.54
2035	4.31	3.33
2040	4.18	3.13
2045	4.04	2.95
2050	3.90	2.76

Source : Dhar et. al., 2013

Labour participation transitions

By 2030, 68 per cent of the total population will comprise of men and women in the working age group of 15-64 years (Figure 11), and this would continue to remain so through to 2050. The dependents i.e., children (below 15 years) and elderly population (above 64 years) will reduce slowly from 35 to 32 per cent. Yet the growth within this segment will be the opposite – the population of the elderly will increase rapidly and that of children will reduce due to declining fertility rates. A high share of working group population implies that the demand for transport will continue to remain high since work trips account for a major share of trips. In the cities of

Figure 10. Projected Vehicle Ownership for two wheelers and cars

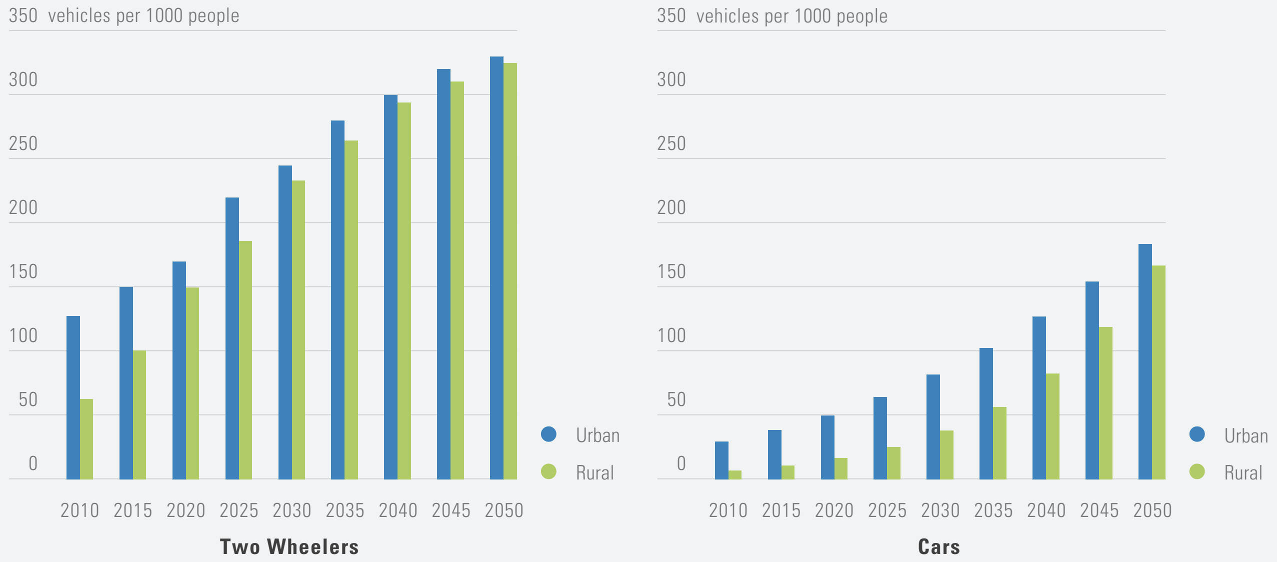
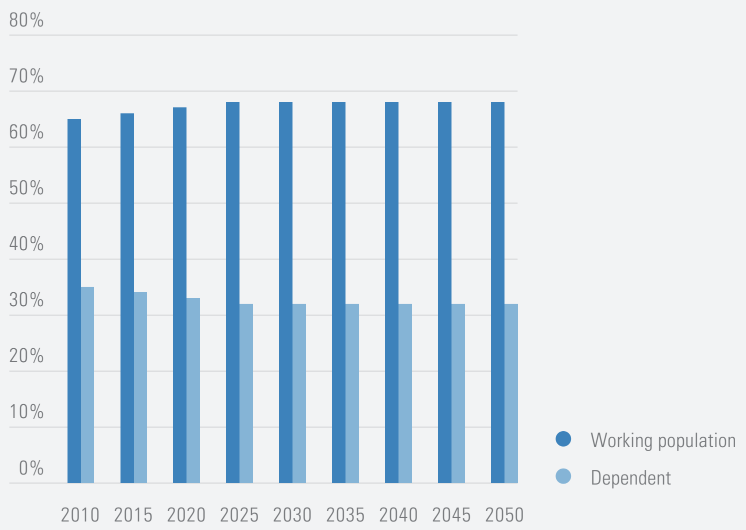


Figure 11. Working and old age population transitions



Source: UN, 2014

Rajkot and Vizag,[1] the work trips accounted for 53 and 39 per cent of overall trips. In addition, mobility demand will also be shaped by a higher participation of women in employment in future. Going to 2050, India is expected to undergo major economic transitions, social and demographic changes and urban transitions, all of which will shape India's future transportation demand.

2.3 Methods

The alternative scenarios for the transport sector have been analysed using the ANSWER MARKAL model. MARKAL is a mathematical model for evaluating the energy system, and has a detailed characterization of technology, fuel mix and investment decisions at the end-use level, while maintaining consistency with system constraints such as energy supply, demand, investment and emissions (Loulou, Goldstein, & Noble, 2004). The ANSWER MARKAL model framework has been used to analyse the Indian energy system (Shukla et al., 2015a), and for the current project the model is based on an intensive and detailed analysis of the transport sector. The innovation in methods have included splitting of demand for urban and intercity passenger transport since technologies vary for the two demands, a richer characterization of technologies, and preparation of detailed supply curves for biomass.

1 Rajkot and Vizag were a part of the UNEP project, and these results are based on surveys carried out for the Low-Carbon Mobility Plans. The reports can be downloaded from http://www.unep.org/Transport/lowcarbon/publications.asp

Photo credit: Centre for Urban Equity

3 Transport Demand Assessment and Modal Choices

3.1 *Passenger transport*

Framework

The transport sector accounts for the largest share of infrastructure investments. Infrastructure investment's share of gross domestic capital formation has increased from 4.9 per cent during 1995-99 to 5.6 per cent during 2007-11, and within that the share of the transport sector has increased from 2 per cent during 1995-99 to 2.6 per cent during 2007-11 (GoI, 2012a). Transport sector investments have long lives (25 to 100 years) and therefore can lead to lock-ins. This suggests the need for long-term demand forecasting and assessment to understand the benefits, costs, and strategies to achieve a low-carbon transition. This section outlines the approach for projecting transport demand for overall, urban, intercity, and further into different modes (Figure 12).

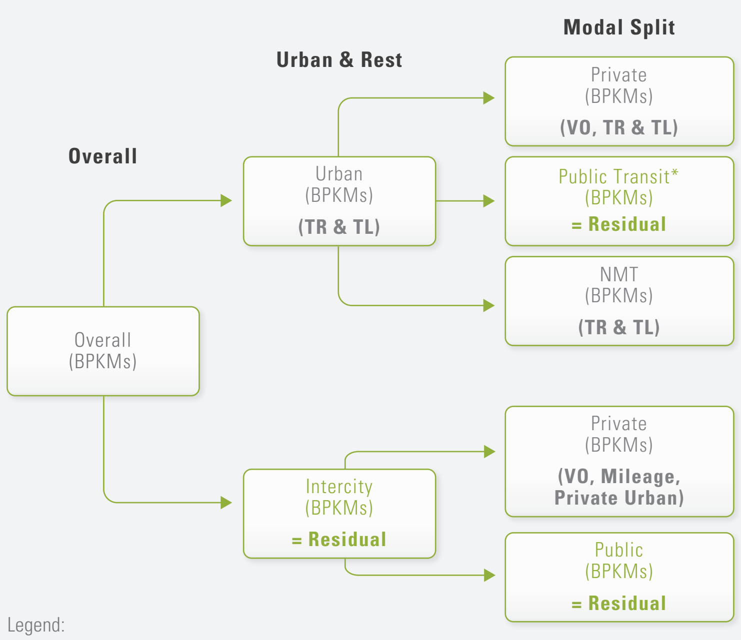
The demand projection follows a step-wise approach (Dhar & Shukla, 2015), where the overall demand is projected first, and this is then is disaggregated into demand for urban and intercity transport. The modal split for both urban and intercity demand is estimated next. The methodologies for each projection are described with the input values in order to allow for a consistent projection across different scenario storylines.

2 In many North American cities, annual car use alone is around 25,000km (Newman & Kenworthy, 2011).

Overall transport demand

The per capita mobility of India is estimated at 5,685 billion pkm in 2010 (Dhar & Shukla, 2015), which is low[2] compared to developed countries. Therefore mobility is expected to increase rapidly with increasing incomes and stabilize in the future following an S-shaped curve. This can be represented through different functional forms, the most commonly used of which include the

Figure 12. Methodology for estimating passenger demand



Legend:

TR: Trip Rate **TL**: Trip Length **VO**: Vehicle Ownership

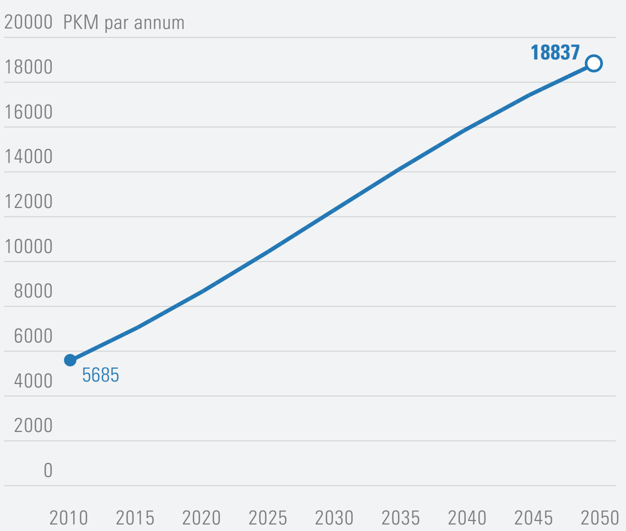
Source: Dhar & Shukla, 2015

** Includes Paratransit*

logistic and Gompertz functions (Singh, 2006). This report uses a logistic function and a saturation value of 20,000km per capita (Dhar & Shukla, 2015). Per capita mobility is expected to increase from around 5685 to 18337 in 2050 (Figure 13).

Elasticity between GDP and transport demand has also been used for demand projections (NTDPC, 2014). This approach, though intuitively simple, can lead to an overestimation in the longer term, e.g., for 2030 the per capita mobility for rail and road alone is more than 110,851 km per annum using demand projections from NTDPC, 2014 (See Appendix, Table C). This value is significantly higher than per capita mobility seen at this income level in any other country (Millard-Ball & Schipper, 2010).

Figure 13. Per Capita Mobility



Equation 2

$$TD_{urban} = \sum_{i=1}^{4} TR_i \times TL_i \times Pop_i \times 365$$

TD_{urban} = Total Transport Demand from cities in a year
TR_i = Average Trip Rate in Category "i" cities
TL_i = Average Trip Length in Category "i" cities
Pop_i = Aggregate population in Category "i" cities
i = Category of city based on population.

The overall demand for passenger transport is expected to increase from around 6,966 billion pkm in 2010 to 31,872 billion pkm in 2050, which is 4.6 times higher than 2010 levels. The growth will be at a CAGR of 3.9 per cent, which is slower than GDP growth.

Urban and intercity transport demand

The urban transportation demand is calculated using a bottom-up methodology (after Dhar & Shukla, 2015), and the demand for intercity passenger transportation is the residual demand, i.e., the demand left over from the overall transport demand once demand for urban transportation is taken out.

Methodology urban transport demand

A wide variety of transport modes are used in India. Public transport is inadequate in the small and medium-sized cities (Pucher, Koratyswaropam, Mittal, & Ittyerah, 2005), and this results in low to almost zero modal shares for public transport (WSA, 2014). Public transport is often provided by para transit modes (auto-rickshaws). Similarly, non-motorized trips are quite high in smaller cities; however, as the cities grow in size non-motorized trips decline (WSA, 2014). Therefore, to understand the variation in travel characteristics across cities systematically, the cities were classified into four broad categories (after Dhar & Shukla, 2015) based on their population (Figure 14). The population transitions in the top 50 cities are provided in the Appendix.

The demand for urban transport was then calculated using equation 2 (after Dhar & Shukla, 2015) on the basis of trip rates and trip lengths, which vary depending on the city category (Dhar and Shukla, 2015).

Average trip rates and trip lengths

The transitions across Indian cities in terms of trip rates and trip lengths have been covered comprehensively in two previous studies: a RITES study carried in 1994, and a study carried by Wilbur Smith for 30 cities in India in 2007.

The average trip length is observed to increase with the size of cities. The average trip lengths in WSA study vary from around 2 to 12km, with the lower value corresponding to smaller cities and the higher value for larger cities. The trip lengths are observed to vary with time (observed from the difference in the 1997 RITES study and the 2007 WSA study) (WSA, 2014). The increase in trip lengths over time also coincides with an increase in vehicle ownership, and as higher vehicle ownerships are expected in future, trip lengths are expected to increase. The trip length in developed countries with high incomes is more than that observed in larger Indian cities, though the average travel time is close to one hour (Table 3). All three countries however have a high ownership of cars, which allows more travel within a fixed time.

This formed the basis of the first hypothesis:

- Trip lengths become longer as cities grow
- Trip lengths become longer as incomes increase.

Household surveys conducted in the cities of Vizag, Rajkot and Udaipur (Table 4) in the UNEP project[3] also supported the hypothesis.

The trip rates in Indian cities also show an increase from smaller to larger cities, with the overall trip rates varying from around 0.8 to 1.70 (WSA, 2014). A greater variation is for the motorized trip rates, which range from 0.3 to 1.1 (Ibid). In the three cities (Vizag, Rajkot and Udaipur), the overall trip rates were between 1.12 and 1.66. The trip rates are higher in the developed countries even with small-sized cities, e.g., in Denmark the largest city has a population of less than 2 million, but the aver-

3 Promoting Low-Carbon Transport in India.

Figure 14. Population transitions in Indian cities in the future

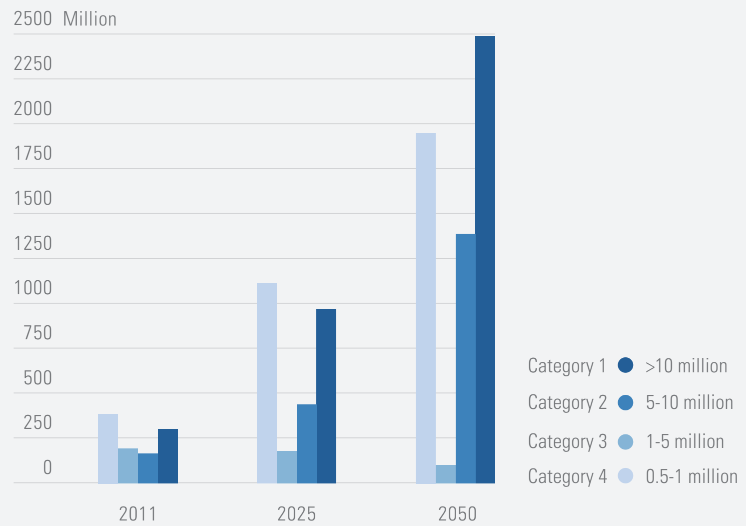


Table 3: Trip lengths and Trip Rates in developed countries

Country	Year	Average Trip Length (km)	Average Trip Rate	Total Travel Time (min)
Denmark	2012	13.60	2.90	57.10
UK	2012	11.71	2.66	59.34
US	2009	16.20	3.79	60.00

Source: National Travel Surveys for respective countries

Table 4: Trip Rates, Trip Lengths and Modal Shares in Indian Cities

	Modal Shares (% of trips)			Average Trip Length (km)		
	Vizag	Rajkot	Udaipur	Vizag	Rajkot	Udaipur
3-wheeler	9.0%	10.8%	11.0%	5.9	4.31	4.47
Bus	18.0%	3.1%	2.0%	11.7	8.47	8.47
Car	2.0%	2.3%	3.0%	9.3	11.67	5.98
2-wheeler	15.0%	35.4%	34.0%	5.8	4.18	5.22
Bicycle	3.0%	10.0%	2.0%	3.2	3.4	5.08
Cycle-rickshaw	1.0%	0.8%			4	
Walk	52.0%	37.7%	48.0%	0.7	1.68	2.54
Average Trip Length (km)				4.1	2.8	3.9
Average Trip Rate	1.66	1.30	1.12			

age trip rate is close to 3 (Table 3). Therefore we hypothesized:

- Trip rates will increase as city size increases
- Trip rates will increase in future and as income increases.

The global values for trip lengths and trip rates were higher than Indian cities, and these were taken as the upper limits for extrapolation, and the values used for demand estimation are as per Dhar & Shukla (2015). The trip rates are expected to vary from 1.2 to 2.3, whereas trip lengths will vary from 3 to 12km (Figure 15).

Equation 3

$$TD_{car} = VO_{car} \times O_{car} \times Mileage_{car} \times Pop \times 365$$

TD_{car} = Total Transport Demand from car in a year
VO_{car} = Vehicle Ownership of car in that year
O_{car} = Vehicle Occupancy of car
$Mileage_{car}$ = Mileage driven in a year
Pop = Population in that year.

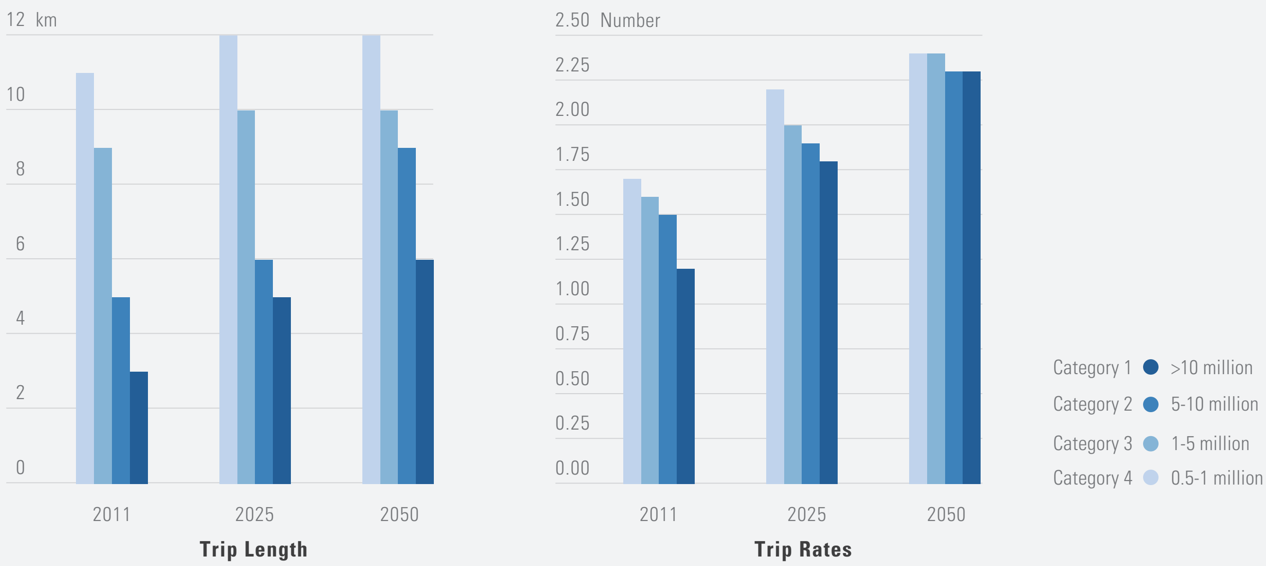
Existing trends point to urban growth that will result in increasing city sizes and consequently longer trip lengths. Trip lengths will also be influenced by higher motorization expected in the future.

Modal shares

The modal shares are estimated for the various means of private transport on the basis of the vehicle ownership, and the demand met from public transport is the residual demand. The vehicle ownership is projected using logistic regression, and the demand for each mode is separately estimated. The following identity, for example, was used for cars (equation 3).

Vehicle occupancy for cars was assumed as 2.2 for the year 2010; however, it was reduced with time. The mileage driven in a year was taken as 8,000 for the year 2010. The value was based on surveys conducted in the cities as part of the UNEP project.

Figure 15. Per capita trip rates and trip lengths (km) for different categories of cities



Source : Dhar & Shukla, 2015

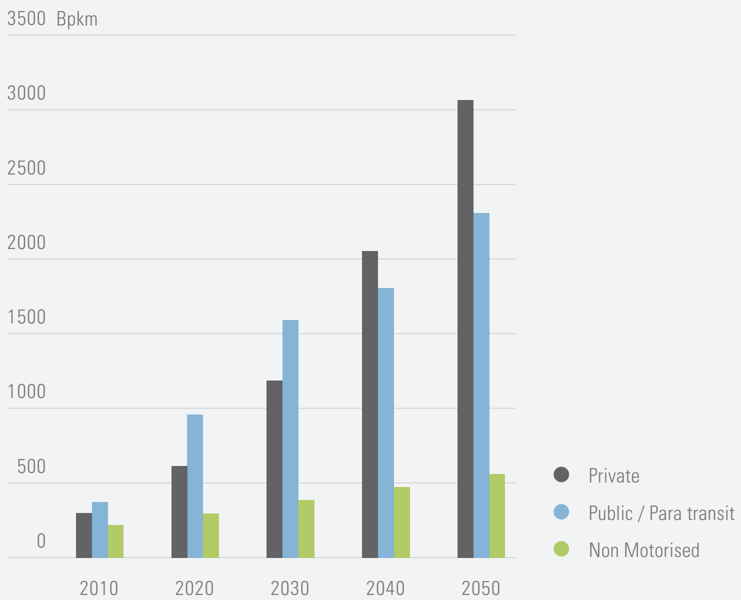
Modal choices for urban passenger transport
Increasing urbanization (Figure 9) would result in a rapid growth in urban passenger demand, reaching 5,932 bpkm by 2050 in the BAU. Given the simultaneous income transition, the increased demand would be largely met through cars and two-wheelers due to a higher ownership of two-wheelers and cars (Figure 10). The demand of public transport and para transit would also increase due to the improvement of urban planning and strengthening of public transport. However, the BAU assumes implementation will be challenging due to financial constraints and a lack of institutional capacity at city level. The mode share of public transport will therefore be overtaken by private transport by 2040 (Figure 16). NMT is expected to grow in line with population growth.

Modal choices for intercity passenger transport
The demand for intercity passenger transport, which also includes the rural demand, is the residual demand from the overall demand once the urban transport demand is subtracted. Intercity passenger demand would increase at a much slower pace compared to the urban transport demand, and reach 25,941 bpkm in 2050 (Figure 17). The demand is mainly met by road-based modes, and the diminishing role of rail would not see a major turnaround.

3.2 *Freight transport*

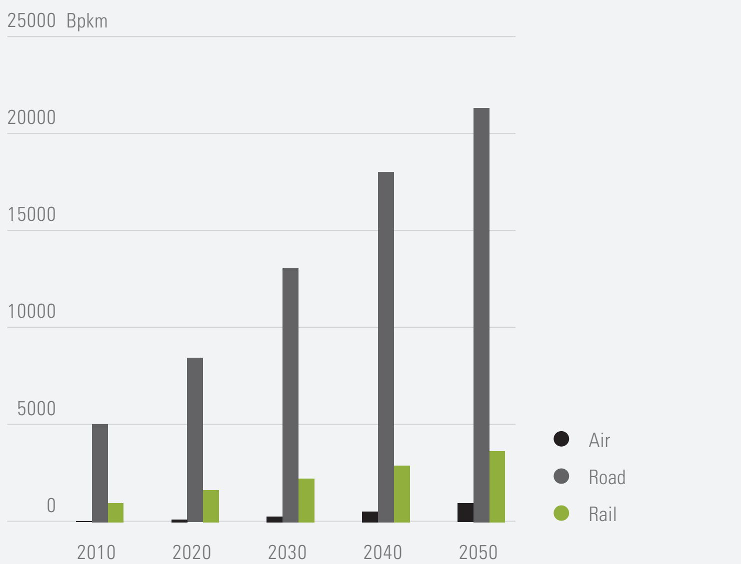
Methodology
Freight demand is closely correlated to consumption levels within an economy. However consumption, in particular of commodities, follows a Kuznets Curve, increasing with increasing incomes and then declining once the income level reaches a certain threshold (Canas, Ferrao, & Conceicao, 2003). The thresholds however vary by commodity, e.g., for steel (Wårell, 2014) and

Figure 16. Passenger Transport Demand – Urban BAU



Source : Dhar & Shukla, 2015

Figure 17. Passenger Transport Demand – Intercity BAU

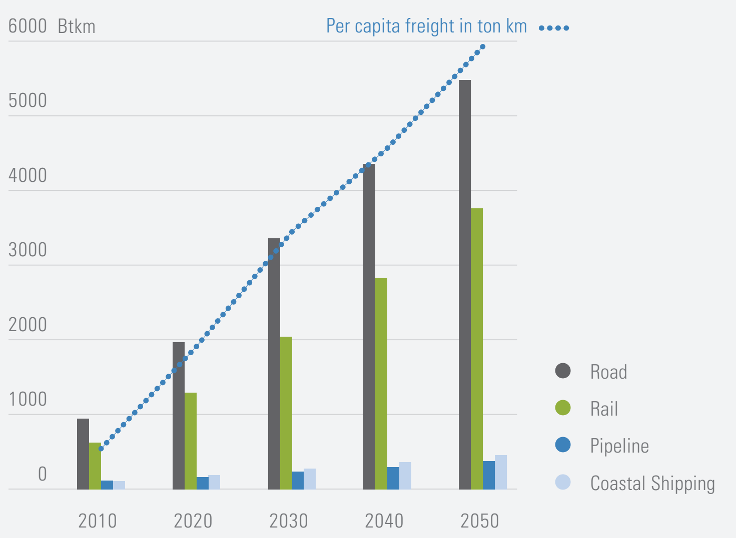


Source : Dhar & Shukla, 2015

aluminium (Jaunky, 2012), a decline in per capita consumption has been already observed in developed countries where a high level of per capita GDP has been reached (Wårell, 2014). India has a low per capita GDP in market exchange terms (WB, 2014), and the per capita GDP even in 2050 would be much lower than levels where GDP and commodity consumption have been decoupled. Besides the estimation of coefficients, the short time series of consumption data available makes it difficult to depict the Kuznets curve using quadratic functions (Wårell, 2014). Therefore a logistic curve was used to project the per capita freight demands. The asymptotic value was taken as 8,000 tkm, which is closer to the level around which EU-28 freight values have peaked (Dhar & Shukla, 2015). The overall transport demand for freight is estimated by the following identity (equation 4).

$$TD_{overall\ freight} = Population \times Per\ Capita\ Freight$$

Figure 18. Freight Transport Demand BAU and Per Capita Freight



Freight transport demand and mode shares

The per capita freight was 1,464 tkm in 2010, and much lower than those prevailing in developed countries (Dhar & Shukla, 2015). In the BAU scenario the per capita demand is expected to increase to 5,941 tkm in 2050, and consequently the overall demand for freight transport is expected to be 10,052 billion tkm in 2050 (Figure 18). The growth will be at a CAGR of 4.4 per cent, which is slower than GDP growth. The estimates for overall freight demand are much lower than those provided in the NTDPC report (NTDPC, 2014), which assumes a flat elasticity of 1.2 and 1.1 between freight and GDP growth. Yet this flat elasticity results in a per capita freight demand of 8,543 tkm by 2031, which is much higher than the per capita freight demand currently within the EU.

In terms of mode shares, not much change is expected, and road and rail will continue as the main modes of transport.

Photo credit: Hendrik Ploeger

4 Passenger Transport: Avoid and Shift Strategies

4.1 Urban passenger transport scenario

Urban transport is dominated by private transport with a large share of two-wheelers. Two-wheelers are mainly four-stroke, while a small share are two-stroke IC engines. Four-wheelers are emerging as a major mode of transport. In India, cars are primarily IC engines using gasoline or diesel as fuel. However, in the last decade, as an outcome of policies mandating natural gas and the subsequent introduction of natural gas infrastructure in cities, (Dhar & Shukla, 2010), CNG four-wheelers have also gained a significant share in the vehicle fleet.

India's INDC highlights the intention of Urban Transport policies, which have a focus on moving 'people' rather than 'vehicles', in which Mass Rapid Transit System (MRTS) would play an important role. Around 236km of metro rail is already operational in Indian cities, and over 500km are under construction. Similarly, BRT systems have been successfully implemented in a number of cities and are expected to scale up rapidly in the near future. Public transport improvements, when combined with changes in land use (design and density) and improvements in walking and cycling infrastructures, can be helpful in reducing CO_2 emissions (See Box 1).

BAU vs sustainable mobility storyline

Historically, Indian cities have a high density and mixed land use, which has resulted in short trip lengths, e.g. the maximum average trip length in Vizag and Rajkot, both of which are million-plus cities, was 4.1 and 2.8 respectively (Table 4) as compared to the average trip lengths of more than 12 in many developed countries (Table 3). However, trip lengths even in Indian cities are increasing as a result of development policies that have not promoted mixed land use. The BAU assumes that urban development will continue along current trends to a low density sprawled type of development with longer trip lengths (Figure 15). Longer trip lengths will discourage the use of non-motorized modes. With inadequate public transport, the share of private modes continues to increase in BAU.

The sustainable mobility scenario reflects a paradigm of urban planning where changes in urban layout, density and land use transport integration (Munshi, 2013; UNEP, 2014) can deliver an overall reduction in demand for urban transport. The sce-

Box1. Low-carbon Transport: Rajkot

The city of Rajkot is located in the state of Gujarat in western India. With an urban population of 1.4 million in 2011, Rajkot is the fourth-largest city in the state. The city is a regional economic centre and an important industrial centre, particularly for engineering and ancillary auto sectors, which cater largely to the cash crop producing agricultural hinterland. It is also a market for agricultural produce. Due to these reasons, the city also has a large floating population. The city is governed by the Rajkot Municipal Corporation (RMC), whose area is 104.86km^2.

Rajkot is one of three Indian cities participating in the UNEP project on 'Promoting Low-Carbon Transport' as a case study for preparation of a Low-carbon Comprehensive Mobility Plan (LCMP). Urban growth was projected through to the year 2031. A transport demand model was developed using the four-stage urban transport demand model, which was modified to incorporate the influence of built form (land use and transport infrastructure) and socio-demographic indicators on travel behaviour, trip generation, choice of mode, and route choice.

In the BAU scenario, transport demand and mobility patterns were analysed, assuming a continuation of existing trends. In alternate scenarios, phased interventions were considered in land use structure, Non-Motorized Transport (NMT), Public Transport (PT) infrastructure and penetration of advanced vehicle technologies. Four alternate scenarios were thus developed. Results show that a combination of these strategies can bring down CO_2 emissions by over 60 per cent in 2031 from BAU. In addition, these interventions would deliver a range of benefits, including reduced air pollution, health benefits and quality of life for citizens.

Source: UNEP, 2014.

nario assumes land use plans will support mixed land use that allows amenities and jobs close to residential areas, locating residences and jobs close to transit stations, reducing trips through substitution with ICT (internet shopping), freight logistics, sourcing localized products, etc. (Sims et al., 2014, UNEP, 2012). The scenario considers that urbanization would not follow the unsustainable trajectory of some of the developed countries, and avoid a high level of motorization mainly through a greater share of public transport. Cities with a higher share of public transport have not only a lower overall share of private transport, but also a lower overall demand due to transit leverage (Newman, Kenworthy, & Glazebrook, 2008). Empirical evidence from Australian cities shows that every 1pkm shift to public transport can reduce the demand for private transport by 4pkm. The sustainable mobility scenario assumes the implementation of demand measures, including parking charges and increased registration taxes will incentivize people to avoid private transport. The scenario assumes measures to facilitate a shift to low GHG emitting modes of transport and discourage shifts from walking, cycling and public transport to private vehicles. The sustainable mobility scenario also assumes that city governments will prioritize infrastructure investments, including public transport, and that improving the quality and reliability of existing systems, integration, access and affordability through fare structures can promote a switch to public transport. There will also be an improvement in walking and cycling infrastructure.

Urban infrastructure is financed through local budgets or funding provided by central and state government. For instance, the national urban renewal mission, a flagship initiative of the Central government, included US$20 billion for financing urban infrastructure including public transport. However, institutional weakness, inadequate demand management and management issues limit the quality of public transport in cities, a trend which is likely to continue in BAU. Consequently, in the BAU scenario, the future demand is largely met by private motorized transport.

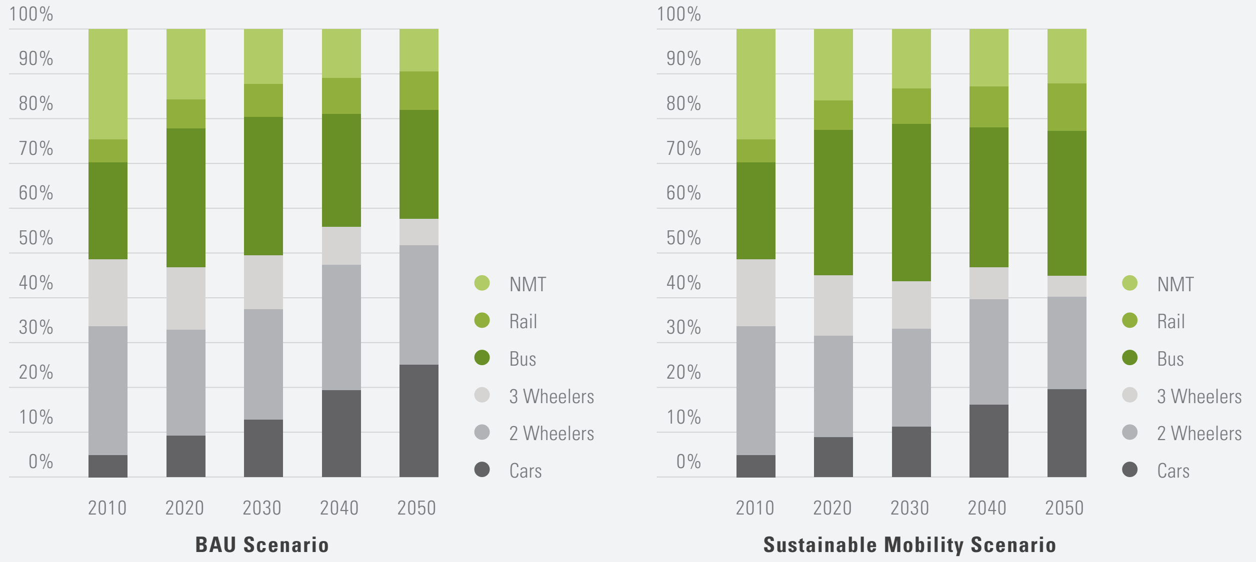
In the sustainable urban mobility scenario, the underlying assumption is that governance and institutional structures will be effective and the planned sustainability reforms will succeed. It is also assumed that cities have the financial resources and institutional capacities to invest in the creation of infrastructures for public transport.

Modal transitions

The modal transitions in the BAU would lead to a growing role for private modes of transport, reflected in the increasing share of two-wheelers and cars (Figure 19). This increasing share is mainly at the expense of walking, cycling and para transit modes. Since the increasing share of two-wheelers and cars are realized in a growing market (Figure 16) the implications in controlling increasing vehicle populations on the road would be substantial, e.g., the two-wheeler population in BAU would increase from around 102 million in 2010 to around 554 million in 2050. The sustainable scenario would see an improved share of public transport and non-motorized transport (Figure 19), and therefore would help in limiting the share of private modes (two-wheelers and cars) to below 40 per cent. By 2050, 30 per cent of private transport demand will shift to public transport, leading to a lower overall demand (430 bpkm by 2050) due to transit leverage. The lower share of private transport would also mean a much lower number of vehicles on the roads, e.g. the number of two-wheelers would be around 388 million in 2050 compared to 554 million in BAU.

Urban planning, including decisions on density, land use, and integration with transport infrastructure can greatly influence travel demand. These factors coupled with investments in public transport and NMT infrastructure can alter the modal shares in the sustainable scenario.

Figure 19. Modal Share: Urban Transport - BAU and Sustainable Scenario



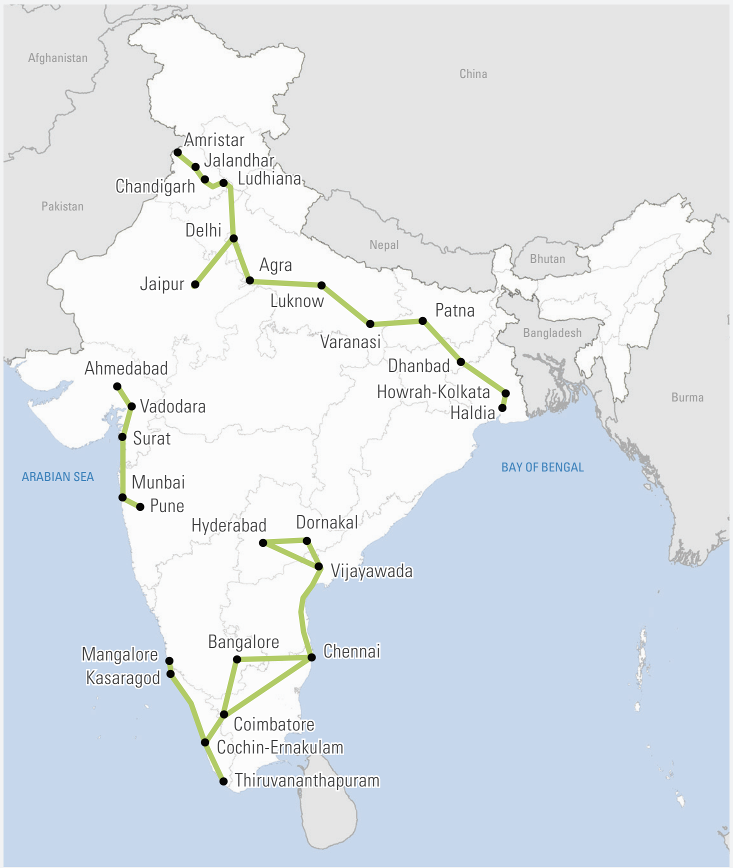
4.2 *Intercity passenger transport*

Rail-based transport has lost much of its share of passenger transport to road-based transport in the past. The government wants to reverse the trend, and aims to achieve this by improving the attractiveness of rail. A key part of the strategy is to improve the average speed of railways, which is expected to increase the competitiveness of rail against air-based transport (Shukla et al., 2015b). The speed increase is going to happen firstly through improvements in existing track and rolling stock infrastructure, e.g. by increasing maximum travel speeds to 160-200 km/hr on the majority of trunk routes. A second part of the strategy is to build high speed train corridors between major urban centres (Figure 20), on which the maximum travel speeds would be beyond 250 km/hr (Shukla et al., 2015b). In addition to improving the speed of journeys, several planned initiatives including infrastructure upgrades, increases in frequency, improved cleanliness, better catering and ticketing services would improve the overall experience of customers travelling by rail.

BAU vs sustainable mobility storyline

Railway improvements depend on increasing investments into rail infrastructures. According to estimates by the National Transport Development Policy Committee (NTDPC), investments in rail transport would have to be increased from 0.3 per cent of GDP in 2011 to 1.2 per cent of GDP by 2028 to restore parity between rail and road infrastructures (NTDPC, 2014). Given that the past transport infrastructure investments in total, even in periods of high economic growth, have not exceeded 2.6 per cent, it may be challenging to allocate 1.2 per cent of GDP for railways alone. Therefore a slower place of track upgrades and implementation of high speed rail corridors is considered in BAU.

Figure 20. Potential HSR lines in India



Source: Goyal A. (2015); GoI (2015)

In the sustainable mobility scenario for intercity transport, the investment bottlenecks are overcome and the investments envisaged by the NTDPC for rail transport infrastructure are realized. The implementation of high speed corridors is expedited and so is the upgrade of the major train corridors to run trains at 160-200km/h. Besides the speed improvements, other institutional changes are expected to improve the efficiency and effectiveness of railways. Railways are also expected to be more integrated with other transport modes to provide a seamless experience for passengers, e.g. better connection with international airports to transfer passengers from long haul flights to other cities, integration of ticketing, etc. Consequently, a major shift towards rail for intercity transport is realized in the sustainable mobility scenario (Figure 21). A study carried out as part of the LCT project shows that the planned high speed rail corridor between Ahmedabad and Mumbai can help increase the share of rail (Shukla et al., 2015b) and improve the connectivity of a number of cities along the route, and deliver a balanced regional development. Results of the study are highlighted in Box 2.

Box2. Ahmedabad-Mumbai High Speed Rail Corridor

The Ahmedabad-Mumbai corridor envisages high speed train services between two rapidly growing major cities in western India: Mumbai and Ahmedabad. Spanning 530km, the corridor, in addition to Mumbai and Ahmedabad, will improve the connectivity for a number of medium and small cities along the corridor, including the cities of Anand, Vadodara, Surat, Vapi and Valsad. With a speed of over 300km/h, this will reduce travel time between Ahmedabad and Mumbai to less than two hours from the current journey time of nearly 7 hours. Ahmedabad-Mumbai links important economic centres in western India, therefore growth in the population and economic activity along the corridor will generate a high demand for passenger travel between the two cities. In 2050, the travel demand is projected to reach 58.2 billion pkms – an increase of four-and-a-half times relative to 2010 levels. Two alternatives for future projections along the corridor were analysed: i. HSR scenario; and ii. No HSR scenario.

In the No HSR scenario, the existing trends continue. The improvement in rail services results in a small increase in the share of rail. Road will continue to dominate. Income effects will result in a significant increase in the share of rail. Between 2010 and 2050, the share of air in total pkms is assumed to double between 2010 and 2050. In the alternate scenario, HSR competes with air, resulting in a reduced growth rate of the share of air. As HSR capacity increases, the share of rail drops post-2020. By 2050, HSR serves one-fifth of the total travel demand in 2050.

The analysis highlights the five key benefits HSR will bring – i. HSR will increase the capacity of rail along the corridor and facilitate a modal shift away from air and road to rail. ii. This will improve the connectivity and attractiveness of the large cities Surat and Vadodara, and around nine smaller and medium-sized cities are situated in direct catchment of the corridor. iii. Compared to air, which will connect only two cities, Ahmedabad and Mumbai, HSR will deliver a more balanced urban growth, leading to overall regional economic development. iv. HSR will deliver significant time savings in comparison to road and rail. v. The modal change away from air and road will also shift the demand away from oil, which is an important consideration for national energy security. This results in a reduction in CO_2 emissions by 0.2MT compared to the No HSR scenario. Since CO_2 emissions depend on the carbon content of electricity, further emission reductions are possible if electricity is decarbonized. Nevertheless, it is emphasized that given the multiple benefits generated, impacts of the Ahmedabad-Mumbai project should be viewed for its larger sustainability benefits beyond CO_2 emission savings.

Source: Shukla et al. (2015).

Modal transitions

The focus on improving rail within the BAU scenario would arrest a further decline in the share of rail; however, investment and institutional bottlenecks will limit the growth. The sustainable scenario, due to a full implementation of measures for improving rail, will result in an increase in the share of rail from 14.5 per cent in 2010 to around 30 per cent in 2050 (Figure 21). The 30 per cent share for rail was taken as the upper bound in the model as even in Japan, with its extensive rail infrastructure, the modal share of rail has been around 27 per cent. In absolute terms by 2050, the railways will meet a demand of 7,004 bpkm, which is more than seven times the demand met by railways in 2010.

Increased investments for improving the efficiency of railways and building high speed corridors are a way to address the declining rail share in total intercity transport kilometres.

In the HSR scenario, due to an increased share of rail, the demand for road-based transport and air declines.

4.3 CO_2 reductions from passenger transport due to sustainable mobility

Private vehicles, especially passenger cars, are on average considered to be more CO_2-intensive than public transport modes. Several developed countries therefore have mandated fuel efficiency standards, or conversely set limits for the average CO_2 of new cars, e.g, the European Union has set a standard of 130 gCO_2/km for cars. Considering an average vehicle occupancy of 1.5, cars would still emit around 97 gCO_2/km. By comparison, public transport modes have a much lower carbon footprint (Table 5), and therefore promoting public transport can lead to a shift of demand

Figure 21. Modal Share: Inter City Transport - BAU and Sustainable Scenario (Bpkm)

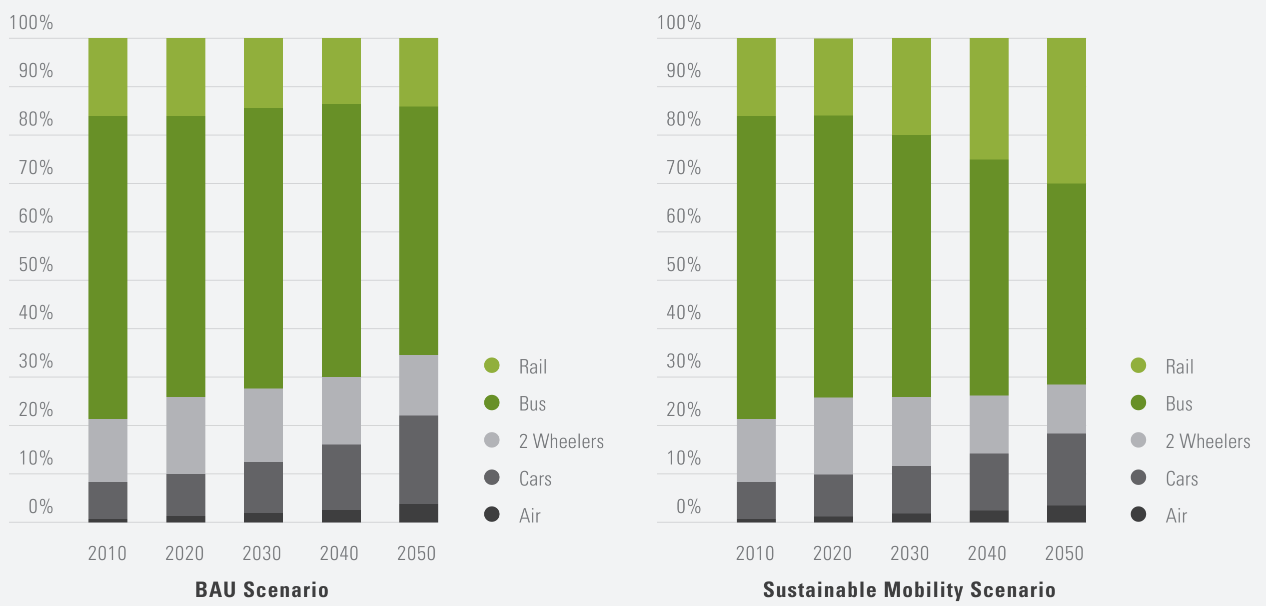


Table 5: Typical characteristics of different transit modes

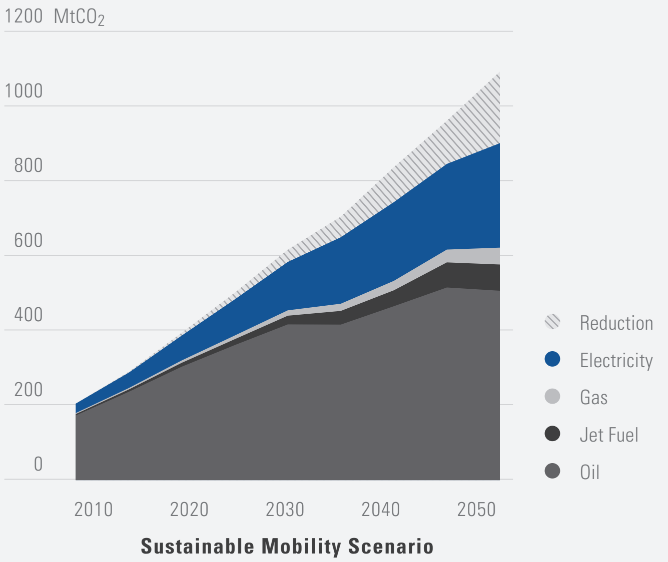
	Bus Rapid Transit	Light Rail system (Trams)	Metro
Typical Capacity (passenggers per line in one hour)	10,000 to 20,000 (Sometimes going to 40,000 Bogota BRT)	10,000 to 20,000	12,000 - 45,000 (Sometimes going upto to 80,000 Hong Kong Metro)
Typical Costs (Million per km of length)*	5 to 27	13 to 40	27 to 330
Existing Networks in 2011*	2139	15000	10000
CO_2 per passenger (gCO_2/pkm)*	14 to 22	4 to 22	3 to 21
Typical Fuel	Diesel	Electricity	Electricity

*Source: * IEA, 2012 Energy Technology Perspectives and Author estimates*

and lower emissions. Public transport can result in reduced travel demand due to transit leverage, resulting in further reduction of CO_2 emissions.

Given rail is highly efficient in terms of energy used per passenger kilometre, an increased share of rail delivers a very sizable reduction in energy consumption in the long-term and, therefore, contributes to energy security.

Figure 22. CO_2 Emissions Reduction by Sources – Sustainable Mobility



The energy reductions also provide a significant reduction in CO_2 emissions, which get further enhanced when electricity is decarbonized due to a higher share of renewables and nuclear within the HSR plus low-carbon scenario.

Rail-based transport is less CO_2-intensive relative to road-based modes of transport (Sims et al., 2014), and is also more flexible in terms of fuel options, e.g. using electricity can help in reducing the CO_2 emissions for intercity transport. In the sustainable scenario, modal shifts and demand reduction help in reducing the CO_2 emissions, and more importantly in putting the CO_2 emissions on a reduced emissions trajectory in the longer term (Figure 22). The cumulative reduction for the period through to 2050 is 2,104 million tCO_2, and the emission level in 2050 is 17.5 per cent below the BAU level. The CO_2 reductions consider a similar CO_2 intensity across the two scenarios.

Strengthening public transport at the city-level can result in CO_2 reduction, and can be one of the significant wedges for mitigation. Combined with sustainable intercity transport strategies, it can reduce about 2,104 million tonnes of CO_2e for the period 2010-2050.

4.4 Co-benefits of sustainable mobility

Energy savings

Sustainable mobility can have a major impact on the final energy demand from transport, especially in the long term (Figure 23). In 2030, the energy demand is lower by 9.1 per cent compared to BAU; however, by 2050, the reduction in energy demand more than doubles to 21.6 per cent.

Air quality

Air quality has been a concern within Indian cities, and emissions from vehicles have been a target of policymakers. Around 2000, discussions started around the first auto fuel policy, which was implemented in 2003, providing a roadmap for implementing standards for vehicles and fuels to limit air pollution. As of 2010, all the metro cities were following the Euro IV (which is referred to as Bharat Stage IV), and the rest of the country was at Euro III (Mohan, Goel, Guttikunda, & Tiwari, 2014). Now a new auto fuel vision and policy that provides a roadmap through to 2025 has been put forward for implementation. It is proposed that the entire country will switch to Euro V by 2020 and Euro VI by 2024 (Figure 24).

Figure 23. Energy Demand and Savings – Sustainable Mobility

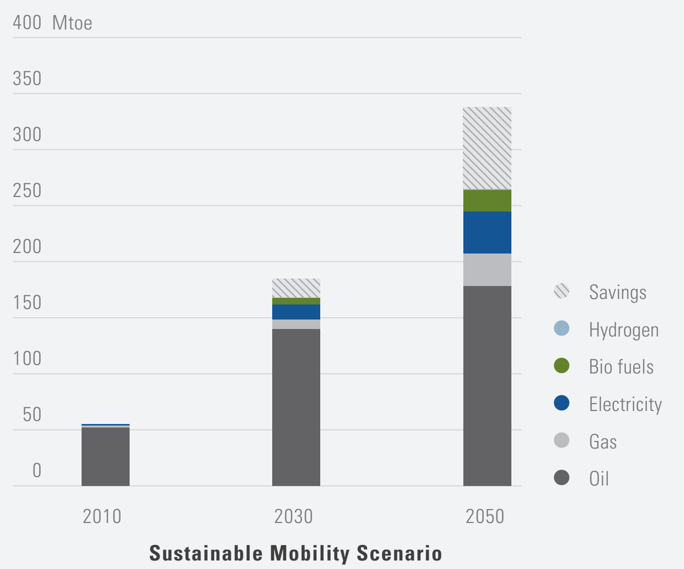
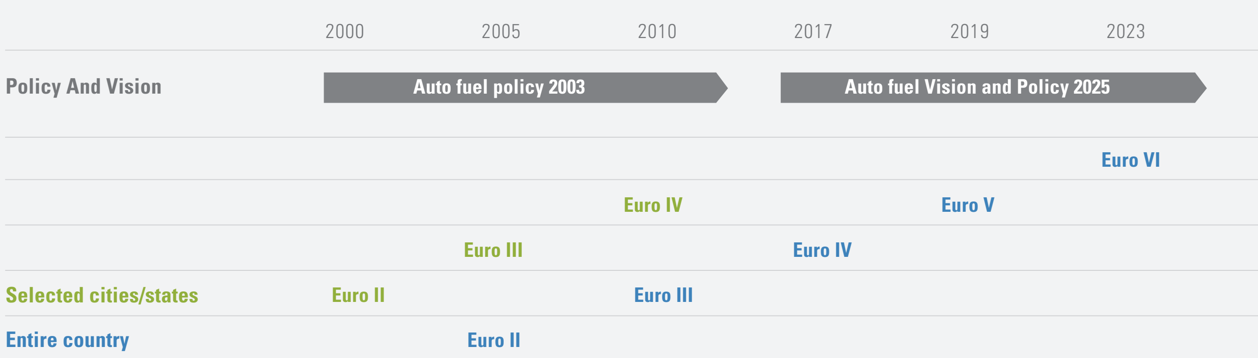


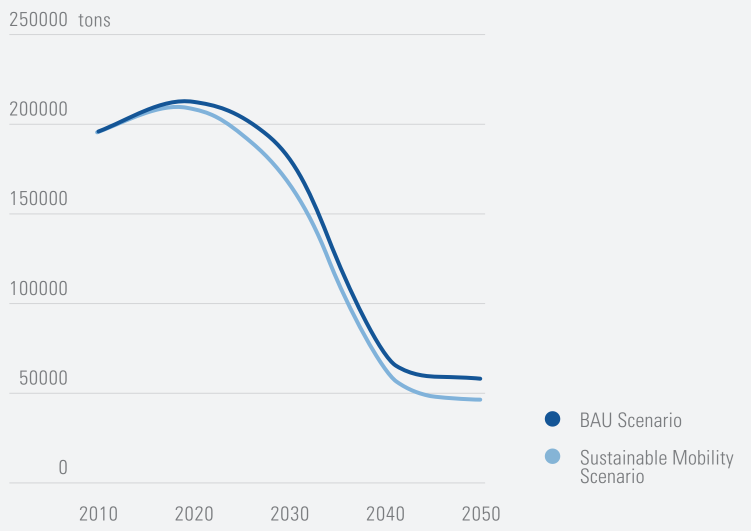
Figure 24. Auto Fuel Policy: Implementation and future roadmap



Source: Adapted from: GoI (2014)c; GoI (2003); ICCT (2013)

Due to an improvement in standards for vehicles post-2020, in the BAU scenario local pollutants, e.g., PM2.5 would start to decline and this would generally improve the air quality in the cities. The sustainable mobility measures considered in this analysis would marginally improve the situation; however, the gains will not be immediate (Figure 25).

Figure 25. Annual Emissions of PM 2.5



Improved access

Indian cities have high densities, and to improve accessibility for all socio-economic groups it is important to improve the design and infrastructure for walking and cycling, which are the dominant modes for poorer people. It can also ensure the longer term sustainability of these modes.

In the case of intercity transportation, improving rail infrastructures (e.g. high speed rail) can reduce journey time not only between larger cities, but commuters living in smaller towns and cities can also benefit. This is quite different from air transport, which can only provide point-to-point connectivity. Therefore unlike air transport, a faster rail system can promote a more balanced development.

Improved safety and equity

Better design of roads and traffic calming measures can reduce accidents. Since a disproportionate number of people killed in road accidents are pedestrians and cyclists, improved road design can help in improving safety, especially of cyclists and pedestrians. Since cycling and walking are the most common modes in Indian cities (UNEP, 2014; WSA, 2014) for socio-economically weaker groups, an improvement in safety will promote greater equity among road users.

Photo Credit: Biswarup Ganguly

5 Intercity Freight Transport

Road and rail have dominated freight transport, with road seizing a larger share of demand (Figure 4). Historically, Indian Railways dominated the inland movement of goods. Over time, economic growth led to a significant demand for freight transport; however, rail transport infrastructure was inadequate to meet the growing demand, resulting in the share of road transport in total freight traffic increasing at a faster rate (RITES, 2009). However, there is a focus on restoring the prominence of rail by building Dedicated Freight Corridors and improving the energy efficiency of locomotives. India aims to enhance the share of railways in total land transportation from 36 to 45 per cent, and therefore replace freight's reliance on less efficient diesel-operated road traffic.

5.1 BAU vs sustainable logistics scenario

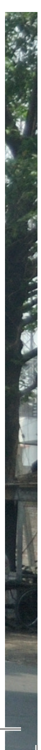
The policy interventions for freight are targeted towards giving preference to movement of freight through rail (NTDPC, 2014). Rail is also more energy efficient and can therefore help in reducing CO_2 emissions (Sims et al., 2014). The implementation of the policies for improving the share of rail in BAU is considered to be slower on account of limitations to financing and institutional weaknesses. Financial constraints are expected in the BAU since the policy goals would require a substantial scale up of investment into transport infrastructures. The sustainable logistics scenario considers faster implementation of Dedicated Freight Corridors (DFC) and their improved integration within industrial corridors and port infrastructures to shift the demand to rail.

The sustainable logistics scenario also considers reduction of freight demand as a second strategy. In a stylized manner, the idea of demand reduction is explored for reduced transportation of coal for power generation, and is referred as the 'coal by wire' strategy (Shukla, Dhar, Victor, & Jackson, 2009).

Dedicated freight corridors

The Government of India has initiated the Dedicated Freight Corridor (DFC) project, which will develop transport corridors dedicated for freight transport in order to facilitate faster freight transport and meet market needs more effectively (DFCCIL, 2011). In addition, creating this extensive infrastructure will facilitate the growth of industrial corridors and logistic parks, leading to regional and national economic benefits. The decision to undertake the ambitious DFC project was to meet the rapidly rising demand for freight transport, and recognized the inadequacy of the existing rail network to meet this demand.

In the first phase, the Western Dedicated Freight Corridor (1520 km) and Eastern Dedicated Freight Corridor (1856 km) are being constructed (Figure 26). Based on estimates outlined in the INDC, the DFCs are expected to reduce emissions by about 457 million tonnes of CO_2 over a 30-year period. A UNEP study on the Western DFC showed that DFCs can help in reducing CO_2 emissions, and the reductions are much higher when the electricity is also decarbonized (Box 3). Traditionally, the rail tracks have been used for both passenger and freight, leading to congestion and inefficiency. The Dedicated Freight Corridor is expected to increase efficiency of movement. In addition, India will be able to leverage



global economic opportunities through better internal connectivity between production centres and ports. The corridor will facilitate industrial development alongside generating significant jobs in small towns and villages along the route. In the BAU scenario, the implementation of these corridors is expected to be slow due to financial constraints, problems in acquiring land, and other institutional weaknesses. However, the intervention is expected to arrest a decline in the share of rail. The rail share of total freight is expected to increase from 35 per cent in 2010 to 37 per cent in 2050.

In the sustainable logistics scenario, the institutional weaknesses and financial constraints are expected to be overcome to realize the full potential of dedicated freight corridors. All six DFCs are expected to be implemented, and by 2046 it is expected that a full demand of 2,712 billion tkm will be realized. Three-fourths of this demand is assumed to be from road transport (Pangotra & Shukla, 2012). The scenario also expects that besides the construction of railway infrastructures, there is a greater integration with other modes that will improve the overall relevance of rail for freight transport.

Figure 26. Freight Corridors in India

Source : DFCCIL (2011)

Box 3: Delhi-Mumbai Dedicated Freight Corridor

The Western DFC is a part of the larger strategic plan of the Ministry of Railways to strengthen India's rail freight infrastructure. The DFC project was conceived in line with the expectation of high future demand for freight transport in the region, and the need to connect the ports in Gujarat and Maharashtra to the manufacturing centres along the western corridor. The western corridor covers 1483km between Delhi and Mumbai. By 2021-22, the share of container traffic will increase to 80 per cent. The introduction of the corridor is expected to result in a major shift from road to rail-based freight. In terms of energy implications, this will increase efficiency and reduce the demand for oil while increasing the share of electricity and generate significant low-carbon benefits with increasing decarbonization of electricity in the future. By 2046-47, the Western DFC project would reduce annual CO_2 emissions by nearly 81 per cent under the business-as-usual scenario, and by 97 per cent under the low-carbon scenario compared to the 'no project' scenario.

Source: Pangotra & Shukla, 2012.

Coal by wire

Transportation of primary energy, i.e. coal, oil and gas is the largest commodity transported. In 2010, these commodities represented a total of 822 million tonnes transported (Dhar & Shukla, 2015). Coal constitutes the largest freight commodity transported by rail in India. In 2010, a total of 262 billion tkm of coal was transported by Indian Railways, and in the BAU scenario this is expected to increase to 782 billion tkm by 2050 (Dhar & Shukla, 2015).

India has a concentration of coal mines in the east; however, coal power plants are fairly distributed across States (Shukla et al., 2009) and the majority of the coal is transported through an elaborate network of rail. The government has also encouraged power utilities and the private sector to set up large (about 4 GW capacity) coal power plants at the mine mouth to address a shortage of power (Shukla et al., 2009). This strategy means that rather than transporting coal to different states, electricity would to be transported, hence: 'coal by wire' (Shukla et al., 2009). In the sustainable logistics scenario, by transporting electricity instead of coal, the demand for transporting coal would come down from 782 billion tkm to only 313 billion tkm (Dhar & Shukla, 2015).

5.2 Modal transitions: BAU vs sustainable logistics scenario

Rail will retain its share of freight in the BAU. The transportation of all natural gas, crude and oil products by land would shift to pipelines by 2030; however, as the share of energy in the overall basket of goods will reduce, the share of pipelines would go down.

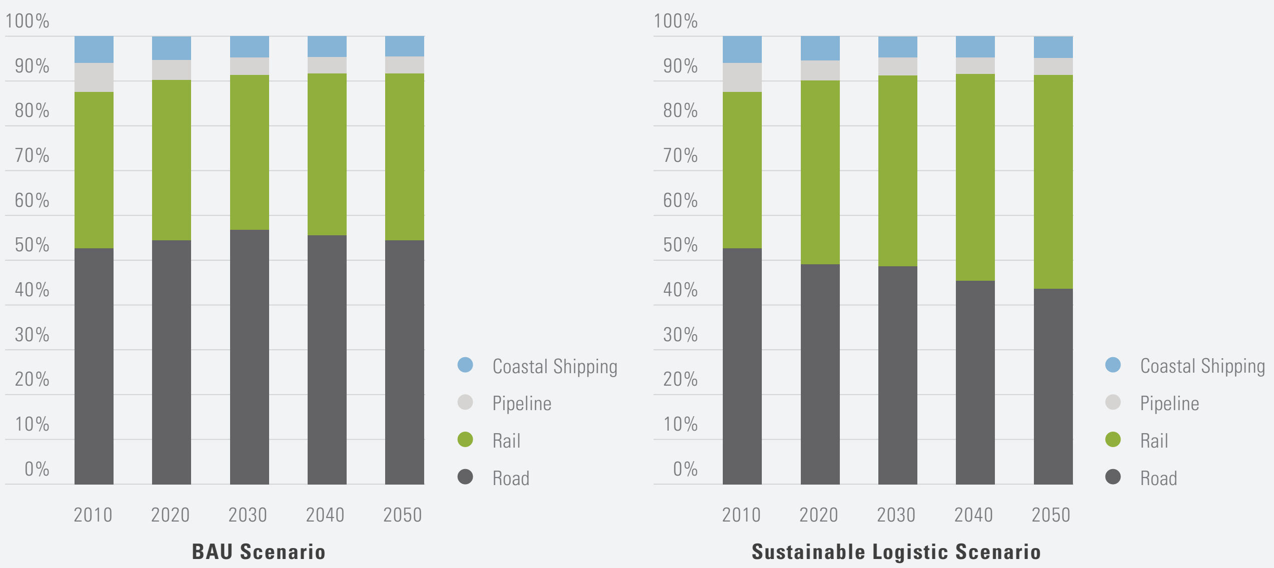
In the sustainable logistics scenario, investments into rail projects to improve haulage and reduce travel times would help to increase the modal share of rail to 48 per cent by 2050 (Figure 27). The increase in the share of rail would be mainly at the expense of road.

5.3 CO_2 reductions

Road-based freight transport is considered to be more CO_2-intensive than rail transport modes (Salter, Dhar, & Newman, 2011; Sims et al., 2014). This is primarily due to a higher energy intensity for road transport (Salter et al., 2011). For the analysis of freight transport, the following assumptions were considered (Table 6) for the base year.

The future would see an improvement in efficiency of both road and rail. In the case of rail for freight transported over the dedicated freight corridors, which is expected to carry around 20 per cent of total freight by 2046, the specific fuel consumption was taken at a much lower 0.008 KWh per NTKM (Pangotra & Shukla, 2012). The higher efficiency of freight transported through

Figure 27. Freight Transport Demand BAU Vs Sustainable Logistic Scenario



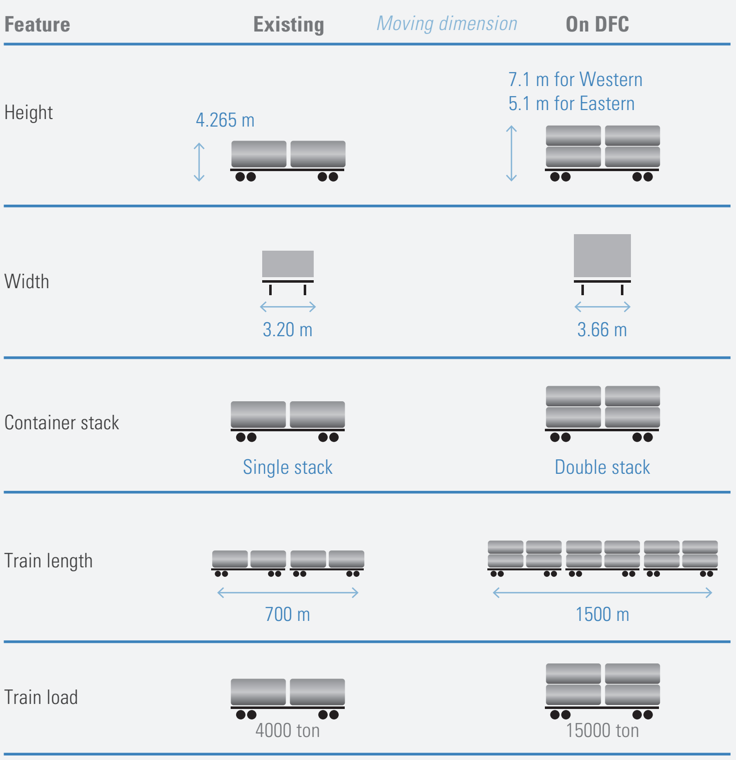
dedicated freight corridors is taken on account of design features (Figure 28), which allow flexibility to carry longer train loads on the same track length.

Table 6: Energy Efficiency for freight modes (per ton km)

Mode	Specific Fuel Consumption	Source
Diesel Truck (20T)	0.0143 litres per NTKM	Assuming mileage of 3.5 km per litre
Rail (Diesel)	0.0045 litres per NTKM	Computed from Annual Statistical, Statement (2009-10), Ministry of Railways
Rail (Electric)	0.011 KWH per NTKM	Computed from Annual Statistical, Statement (2009-10), Ministry of Railways

Source : Pangotra and Shukla, 2012

Figure 28. Comparison of Design features of existing and proposed DFC



Source : DFCCIL (2011)

In the sustainable logistics scenario, a modal shift to rail from road and a demand reduction are helpful in reducing the overall CO_2 emissions (Figure 29). The cumulative reduction for the period through to 2050 is 625 million tCO_2, and the emission level in 2050 is 3.8 per cent below the BAU level. The emission reductions from a shift to rail are limited since the CO_2 intensity of electricity is considered the same as BAU, where the CO_2 emission intensity remains high.

Large infrastructure projects, such as the proposed Dedicated Freight Corridor (DFC), are critical drivers of the national economy and have major implications for achieving low-carbon development goals.

5.4 Co-benefits

Energy savings

Sustainable logistics can have an impact on the final energy demand from transport, especially in the long term (Figure 30). In 2030, the energy demand is lower by 2.6 per cent compared to BAU; however, by 2050 the reduction in energy demand is 4.6 per cent.

Air quality

Sustainable logistics would help in bringing down air pollutant emissions, e.g. PM2.5; however, since these reductions would be distributed geographically over a wide area, the impacts on air quality would not be significant.

Regional development

The Dedicated Freight Corridor (DFC) is not a project for Indian Railways, but rather for supporting industrial development. The Delhi-Mumbai Freight Corridor is therefore creating along with it the Delhi-Mumbai Industrial Corridor (DMIC). The DMIC will develop high impact development nodes as 24 market-oriented centres. These nodes are designated for industrial development and are connected to the DFC, regional ports and hinterland markets (Pangotra & Shukla, 2012). The success of the DFC would largely depend upon the development of industrial hubs along the corridor, and at the same time the DFC would act as a lifeline for the industrial nodes.

Figure 29. CO_2 Emissions Reduction by Sources – Sustainable Logistics

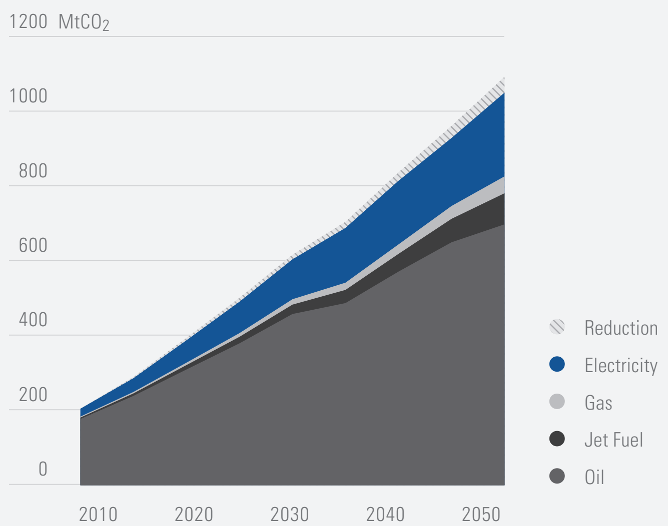
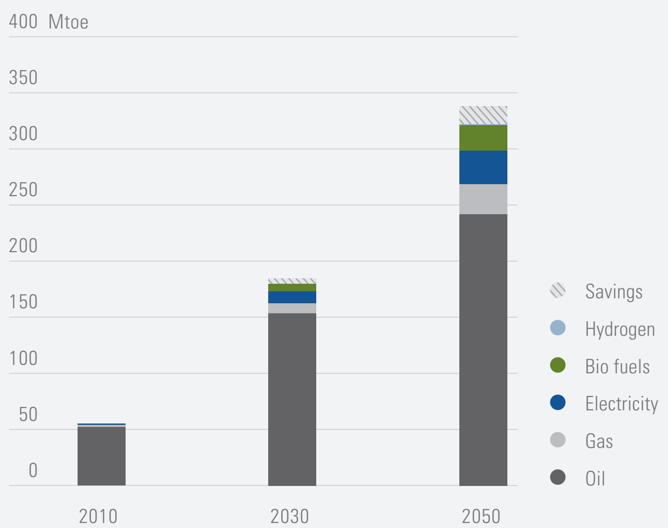


Figure 30. Energy Demand and Savings – Sustainable Logistics

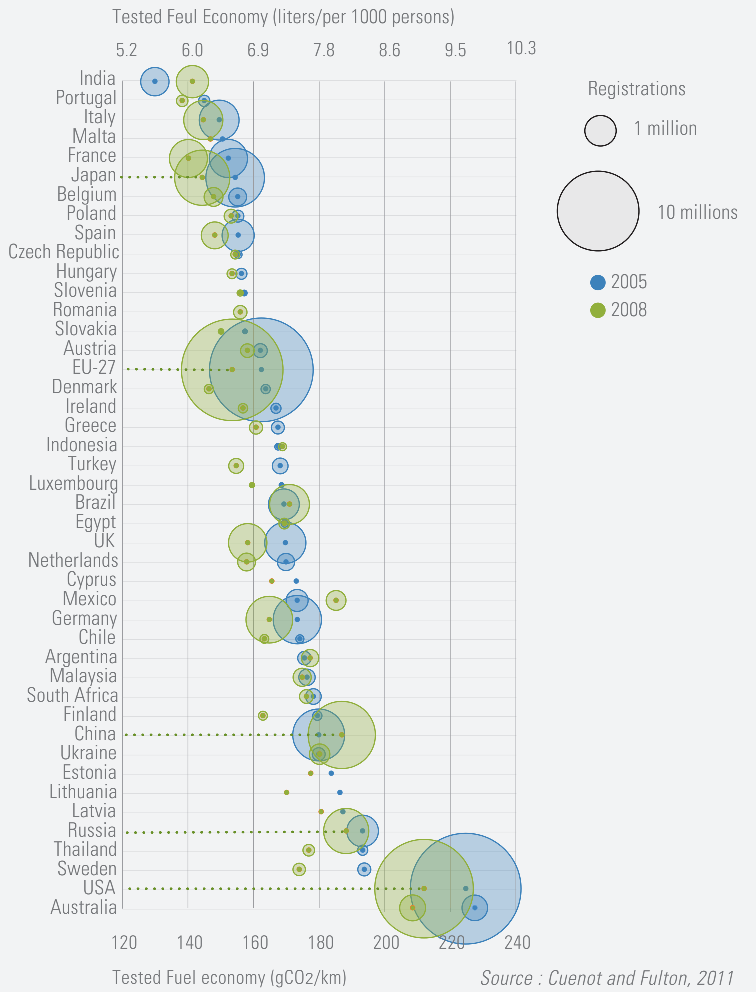


6 Vehicle Fuel Economy

The Indian vehicle fleet is one of the youngest, with the average age of cars and scooters being less than 5 years (Goel et al., 2015). In addition, a large numbers of cars sold are of a small size, and this has resulted in the Indian fleet being one of the most efficient car fleets globally (Figure 31). A number of trends however, indicate that India cannot rest on its current achievements. The first is that the growth rate of cars is faster than the pace of economic growth, and therefore the growth in demand for oil can impact energy security. India imports more than three quarters of its oil, and therefore it can lead to an adverse scenario with regard to the balance of payments. Given the fact that vehicle ownership in India is way below the global average (Figure 32), and incomes will continue to increase, the growth rate of vehicle ownership is expected to remain high in the near future.

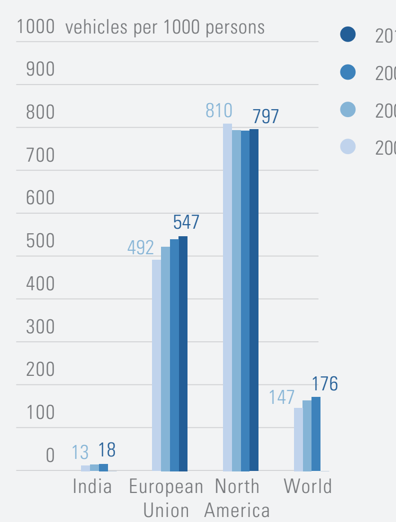
The rapid growth of vehicles especially within the cities is contributing to a rise in air pollutant emissions, particularly PM2.5 and NOx, and is consequently leading to a worsening of air quality. Governments are exploring alternatives to mitigate the externalities from increased private vehicle ownership and use. Since 2011, the Government of India has been considering a

Figure 31. Cross country comparison of vehicle efficiency



Source : Cuenot and Fulton, 2011

Figure 32. Motor Vehicle Ownership



Source: Data taken from World Bank Data Base policy for implementing fuel efficiency labels and standards for vehicles. This is expected to come into effect in 2017. These standards will be based on the weight of vehicles and are expected to become more stringent with time (BEE, 2011).

6.1 BAU vs fuel economy scenario

In the BAU scenario, based on the government's announced policy for fuel economy for cars, it is expected that cars within each weight class would become more efficient. However, increasing incomes will result in a higher preference for bigger cars, and therefore an average fuel efficiency of 5 litres per 100km in 2030 is considered (Figure 33). Post-2030 a further improvement in fuel economy for cars would bring the fuel efficiency below 5 but not below 4l/100km, since increasing incomes are expected to make it difficult to improve average efficiency.

In the fuel economy scenario, the average fuel efficiency improvements are considered to be congruent with targets proposed by the Global Fuel Economy Initiative (GFEI) (Figure 34). These targets are aligned with the needs for vehicle efficiency improvement to remain within the vision for limiting the global temperature rise to 2°C. Therefore more stringent standards are considered, e.g. achieving the GFEI target of an average fuel economy of 4l/100km in 2030 (Figure 36). Post-2030, a further improvement in fuel economy for cars would bring the fuel efficiency to 3l/100km due to a continued focus on fuel economy. This scenario assumes that besides technologies, there would be policies that disincentivize the purchase of bigger cars.

6.2 CO_2 reductions

The improvements in average fuel economy would happen through small improvements over time in the existing drivetrains for petrol and diesel, and by providing flexibility in choos-

Figure 33. Average Fuel Economy of cars

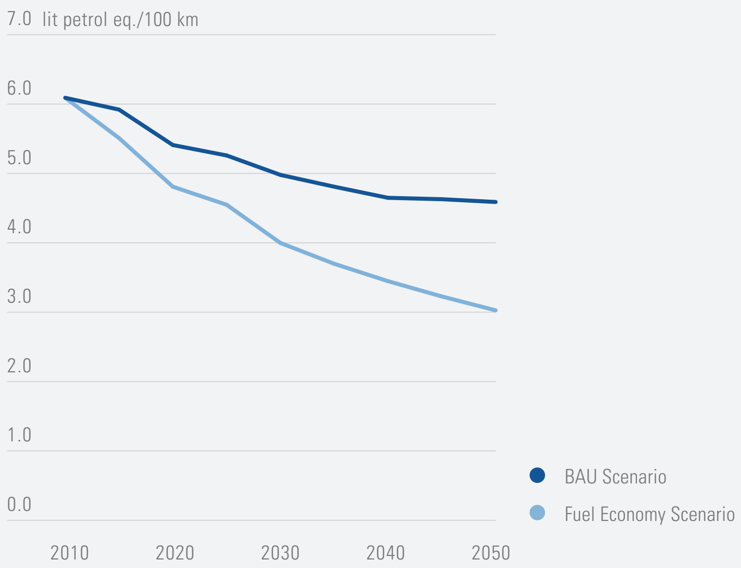
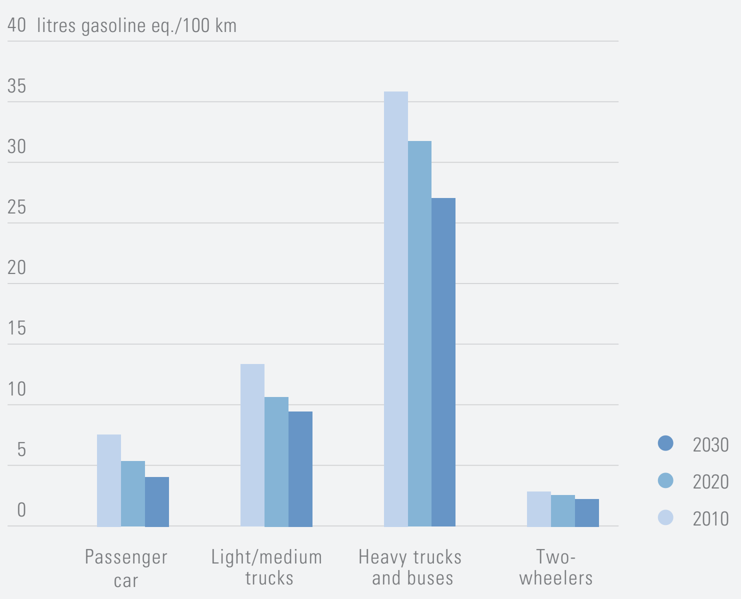


Figure 34. Global Fuel Economy Targets for 2 Degree Scenario



Source: IEA (2012)

Table 7: Alternative Drivetrain Technologies

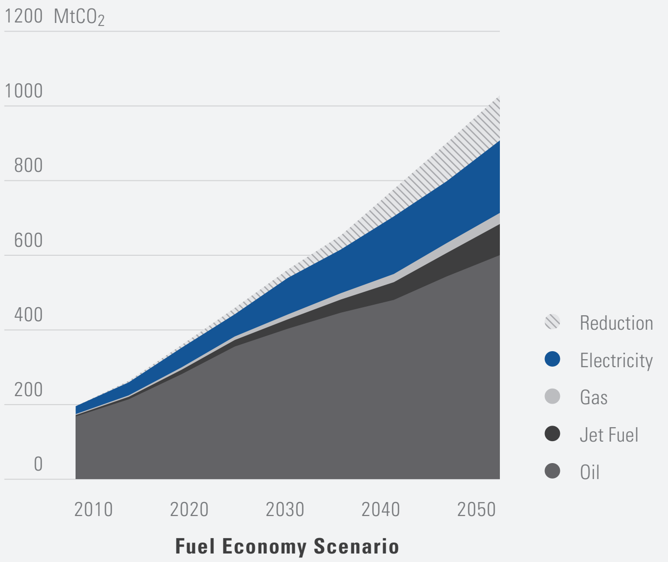
Feature	Battery Electric vehicles	Hybrid Gasoline	Plug in Hybrids	Fuel Cells
Drive Range	100 - 160 km for cars, 60 km for 2 wheelers	Same as gasoline cars	20 - 50 km on battery alone, remaining using ICE	Same as gasoline cars
Drivetrain	Electric Motor	Internal Combustion Engine	ICE, Electric Motor	Fuel Cell, Electric Motor
Energy consumption per pkm (w.r.t to a Gasoline engine) **	70-80% lower	11-22% lower	20-60% lower	55%-70% lower
Typical Fuel	Electricity	Electricity / Gasoline /Diesel	Electricity / Gasoline /Diesel	Hydrogen

*Source ** IEA, 2009; Kobayachi et. al., 2009*

ing alternative drivetrains that can provide more radical efficiency improvement such as hybrids, PHEVs, BEVs and fuel cells (Table 7).

These efficiency improvements translate into a reduction in CO_2 emissions because the conventional drivetrains are based on petrol and diesel, which are currently derived from fossil fuels and therefore very CO_2-intensive.

Figure 35. CO_2 Emissions Reduction by Sources – Fuel Economy



The improved fuel economy envisaged in the fuel economy scenario is helpful in reducing the overall CO_2 emissions (Figure 35). The cumulative reduction for the period through to 2050 is 1,620 million tCO_2, and the emission level in 2050 is 11.8 per cent below the BAU level.

6.3 Co-benefits

Energy savings

Fuel economy can have a substantial impact on the final energy demand from transport, especially in the long term (Figure 36). In 2030 the energy demand is 12.2 per cent lower than BAU. By 2050, this reduction increases to 19.8 per cent.

Air quality

PM2.5 emissions are expected to improve even in the BAU; however, assessment shows that targeted policies for fuel economy can give a further boost to these efforts and result in further reductions in PM2.5 emissions (Figure 37).

Improving the fuel efficiency of cars and two-wheelers could contribute to about 4,100 million tonnes of CO_2e for the period 2010-2050, and is the second largest wedge for mitigation

Figure 36. Energy Demand and Savings – Fuel Economy

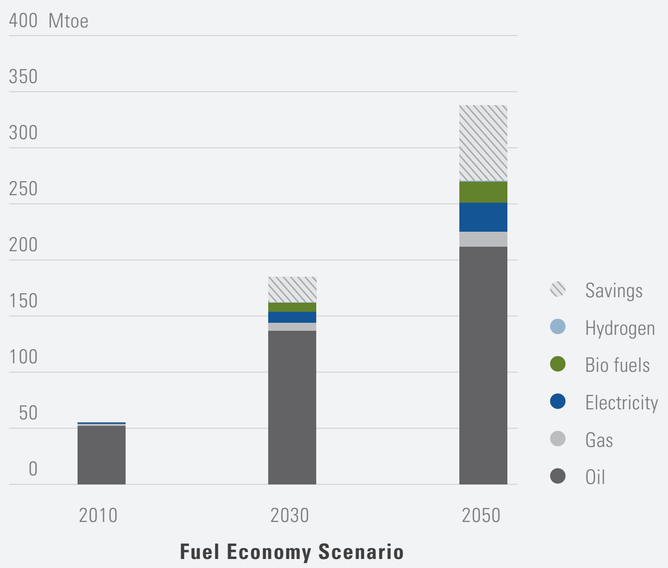
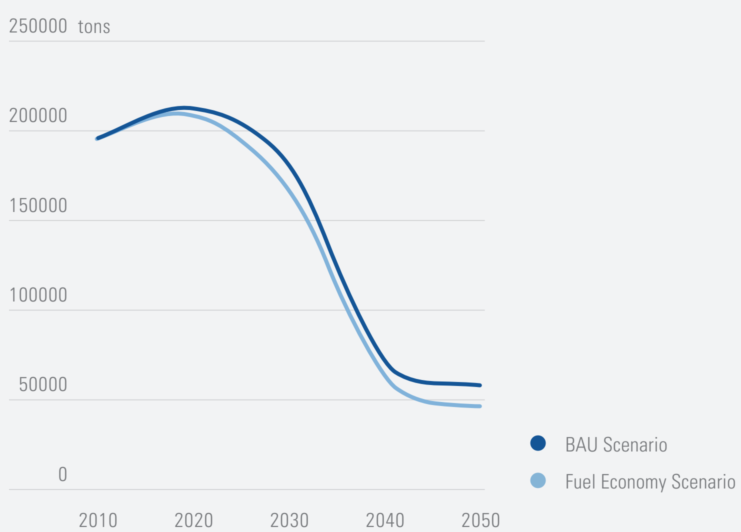


Figure 37. Annual Emissions of PM 2.5 (tons), BAU Scenario and Fuel Economy Scenario



7 Electric Mobility

Electric vehicles are not new to transport. Though the first EV was introduced in the late 19th century, EVs have gained prominence post-1990 as concerns around energy, air quality and climate change have increased. EVs could have positive implications for national energy security, improving local air quality, GHG mitigation, and in the long term facilitate an increase in the renewable energy share in the electricity sector. Ambitious national targets, local government plans, subsidies, incentives and investments in R&D have resulted in an increasing share of EVs in several countries.

Electric vehicles have caught the imagination of policymakers globally, and many countries are providing incentives for hybrids and electric vehicles (Shukla et al., 2014). In India, policymakers are also enthused by the prospect of EVs, and a comprehensive roadmap for electric vehicles has been announced (GoI, 2012). In 2013, the National Electric Mobility Mission Plan (NEMMP 2020) was announced by the Government of India to incentivize the use and production of electric vehicles (EVs) in India, with the objective of enhancing energy security and mitigating the adverse environmental impacts of vehicles. The policy envisages an estimated investment of $4-4.5 billion, both by the government and private sector into R&D, and in setting up electric vehicle infrastructure. The EV market in India is at a nascent stage, and the following sections looks

Table 8: Policy Instruments in BAU and EV Scenario

Policy Instrument	BAU Scenario	National EV Policies Scenario
Economic Instruments for EV		
Excise Duty/ Import Duty	A duty of 12% applies to EV and hybrid cars. This is at par with small gasoline or diesel cars (engine capacity less than 1500 cc and length less than 4m). Batteries, motors and other parts for EV have no preferential treatment.	Considers full duty exemption till 2025 on cars and batteries. Post 2025 tax rates increased and tax parity is achieved by 2040.
Sales Tax (VAT)	No concessions for VAT considered.	Considers half the VAT in BAU to factor for the positive local environmental benefits till 2025 and thereafter an increasing tax rate with tax parity by 2040
		Overall a lower capital cost compared to BAU.
Incentives for Public Transport		
Buses	In BAU, priority for buses and BRT systems is expected in all cities with more than a million inhabitants however no special incentive for electric buses.	Capital costs lower due to economic incentives and better provisioning of infrastructures for charging.
Infrastructures for EV		
Charging infrastructures	The BAU considers no specific investment into charging infrastructures and as a result EV makes use of spare capacity of grids. Therefore a maximum share constraint of 20% put on 2W and cars by 2035.	An intelligent electric grid which can allow usage of EV both as storage and source of electricity combined with a higher capacity grid. *As a result a 10% higher investment on transmission & distribution is assumed. Meanwhile maximum share of EVs among 2Ws and cars is increased to 40% by 2035.*
Dedicated lanes for cycles	Funding from central government is expected to help create cycle lanes and a better infrastructure for cycles in the cities. Motorized 2-wheelers, however, are not allowed on cycle lanes.	E2W with maximum speed of 25 km per hour allowed on the cycle lanes. This would increase attractiveness of E2W and *shift non EV bicycles to EV.*

Source: Shukla et. al., 2014

at what the EV strategy can achieve for CO_2 mitigation and the co-benefits of EVs.

7.1 BAU vs EV scenario

Due to strong policy support and an active interest at the global and national level in electric vehicles in electric vehicles in the BAU scenario, we project a reduction in the cost of batteries and electric vehicles in that scenario. The cost reductions are however faster for the EV scenario based on advanced battery technologies (Shukla et al., 2014).

In India, EVs have been mainly using lead acid batteries, which have limitations in driving range, top speeds and acceleration (GoI, 2012b); however, despite these limitations they have found a modicum of success in the cities, e.g. as a para transit mode in electric rickshaws. A broader acceptance would however require overcoming the aforementioned technical challenges. The BAU scenario therefore assumes that the less expensive technology options that have their limitations, e.g. in terms of driving range, would be limited to servicing urban transport demand, and more expensive EVs, e.g. those with a higher driving range, would have no constraints imposed.

In the BAU scenario it is assumed that capital subsidy will be provided for electric vehicles as proposed within the National Electricity Mobility Mission Plan (NEMMP) 2020 (Shukla et al., 2014). A list of other supporting policies and how they vary between the BAU and EV scenarios are provided in Table 8.

The CO_2 reductions from EV depend largely on the emissions intensity of the electricity. Currently, India produces a large share of electricity from coal, and as a result the electricity is highly CO_2-intensive. In the future, even within the BAU scenario, electricity would be decarbonized, though the decarbonization would be very significant in strong climate stabilization scenarios, e.g. in the 2°C scenario.

7.2 EV diffusion within light duty vehicles

Two-wheelers will continue to dominate as a major mode of transport in cities. The current stock of motorized two-wheelers uses petrol-driven internal combustion engines. In the BAU scenario, EVs based on lead acid batteries would become viable in the short term; however, due to limited driving range, these will have a small share. The advanced EVs with larger battery capacities and longer driving range would still be relatively expensive, and therefore do not penetrate the market until 2030 in the BAU (Figure 38).

In the EV scenario, however, stronger policies, infrastructures and financial incentives boost the share of low cost E2Ws in the market. However, due to limitations of power and driving range capacity, these variants do not retain the same growth post-2020. The more expensive E2Ws, with higher power and driving range, remain more expensive compared to conventional two-wheelers. These variants however become a competitive option along with hybrid E2Ws post-2030.

Four-wheelers would play a major role for transportation due to the strong demand for private passenger transportation. E4Ws currently have a negligible share of the market, and in the BAU scenario E4Ws having a limited driving range and prices below US$15,000 would become viable from 2030 onwards. However, E4Ws with a higher payload capacity and a longer driving range would not become viable by 2035. In the EV scenario, due to the incentives for electric vehicles (Table 8), small electric cars become viable from 2020.

Financial incentives and infrastructure will allow for a high penetration of electric two-wheelers if enabling conditions are made available. Electric cars would however need stronger supporting policies.

Figure 38. Shares of EVs in 2 wheelers and cars

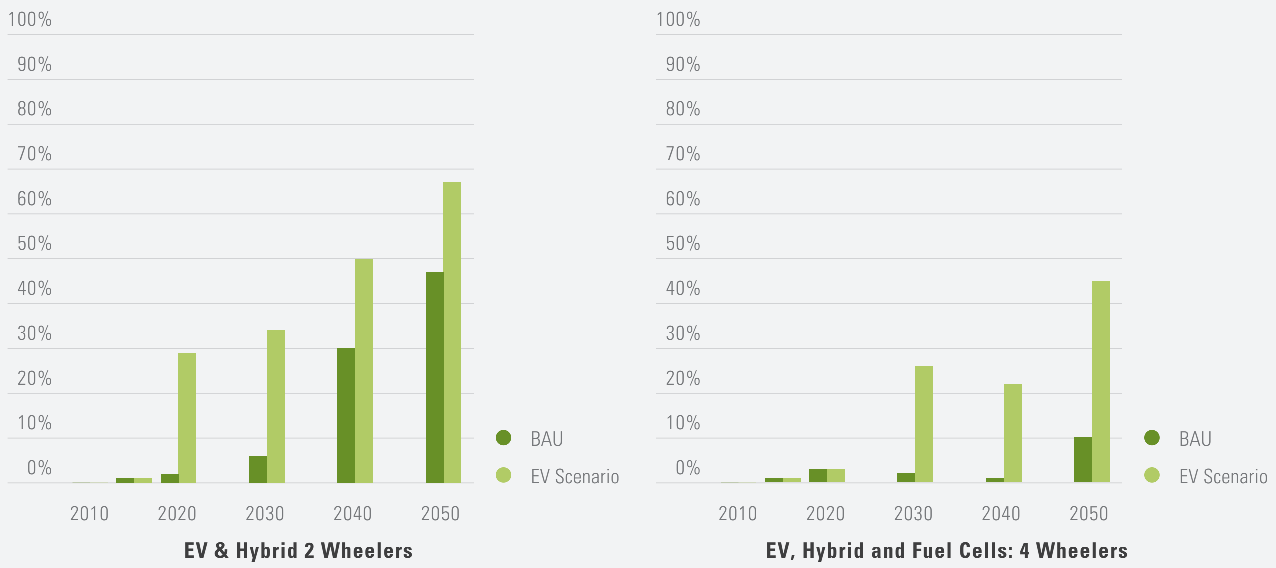
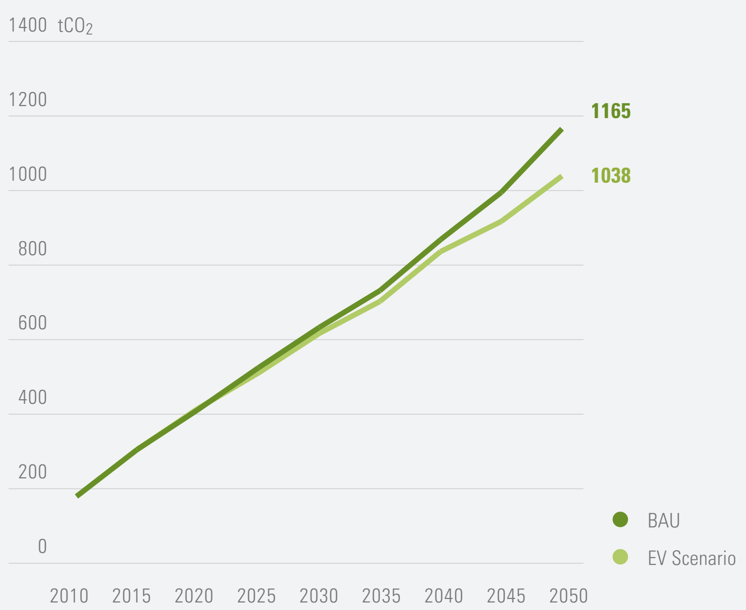


Figure 39. CO_2 Emissions in BAU and EV scenarios



Rapid diffusion of EVs will increase electricity demand; however, this will not require major capacity addition.

EVs policies can bring significant air quality benefits. Electric mobility can deliver the largest wedge for CO_2 mitigation; however, this relies on the cleaning of electricity.

7.3 CO_2 reductions

In the BAU scenario, the transport sector's CO_2 emissions increase at a slightly slower rate than the increase in energy demand. The decoupling between energy and CO_2 emissions is due to the diversification of fuel mix towards biofuels and natural gas, and reduction in CO_2 intensity of electricity. In the BAU scenario, the CO_2 intensity of the grid decreases from 0.80 million tCO_2 per GWH in 2010 (CEA, 2012) to 0.62 million tCO_2 per GWH in 2050.

In the EV scenario a slight reduction in CO_2 emissions is achieved (Figure 39). The reduction is for two reasons: first, CO_2 emissions from electricity generation are slightly lower in this scenario, and second, overall energy demand is lower due to the adoption of more efficient vehicles.

7.4 Co-benefits

Energy security

EV would not be able to improve energy security immediately; however, by 2030 EVs would provide a substantial contribution. The first factor for improving energy security is the reduction in overall demand for energy in the EV scenarios compared to BAU (Figure 40). The second factor that contributes to improving energy security is the increased diversification of fuel mix away from oil. In the EV scenario, the demand for oil is lower than in the BAU scenario (Figure 41).

The diversification away from oil will lead to a higher electricity demand for transport, and also a matching storage capacity. This could be an opportunity for electric grids to integrate intermittent renewables like wind and solar.

Air quality

In the BAU scenario the emissions of PM2.5 would increase until 2020, and the key contributors to this would be the increasing two-wheeler population along with cars and other motorized transport. Improvements in emission standards and the replacement of older vehicle stocks would lead to a reduction in local pollutants (such as PM2.5) by 2030 and beyond, even in the BAU scenario. EV could however help in addressing the problem on a more urgent basis (Figure 42).

Integration of renewables

Renewables like wind and solar are intermittent, and therefore improving electricity storage in the system would be helpful in integrating more renewables. The Indian INDC has a strong focus on improving the share of solar and wind energy in electricity generation, and EVs can provide battery storage in hundreds of gigawatts (Shukla et

Figure 40. Energy Demand : BAU vs EV Scenario

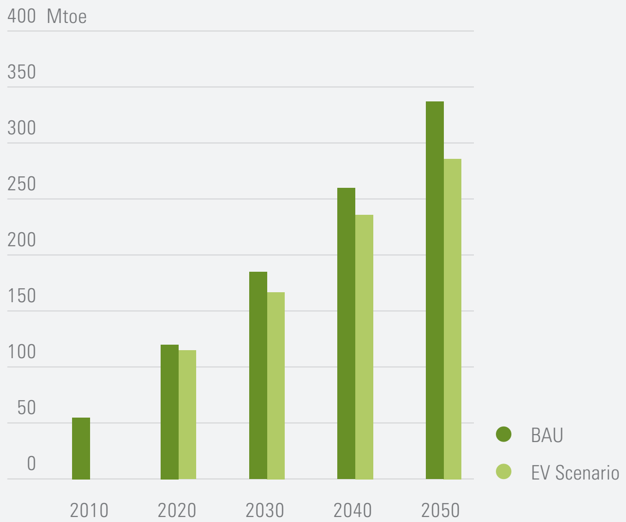


Figure 41. Oil Demand and Savings of Oil in EV Scenario

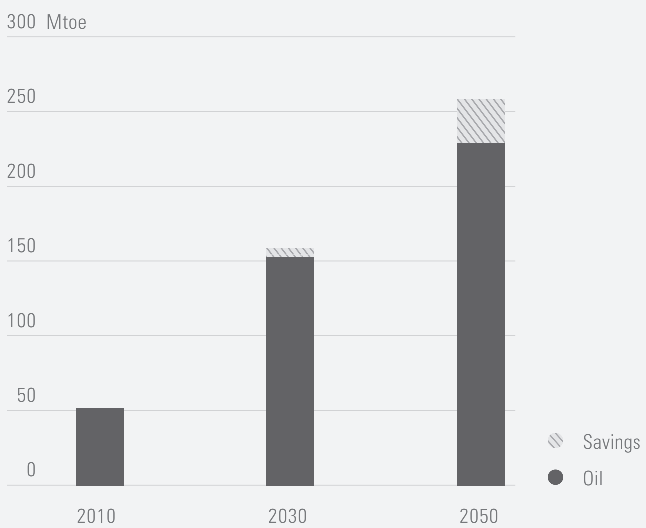
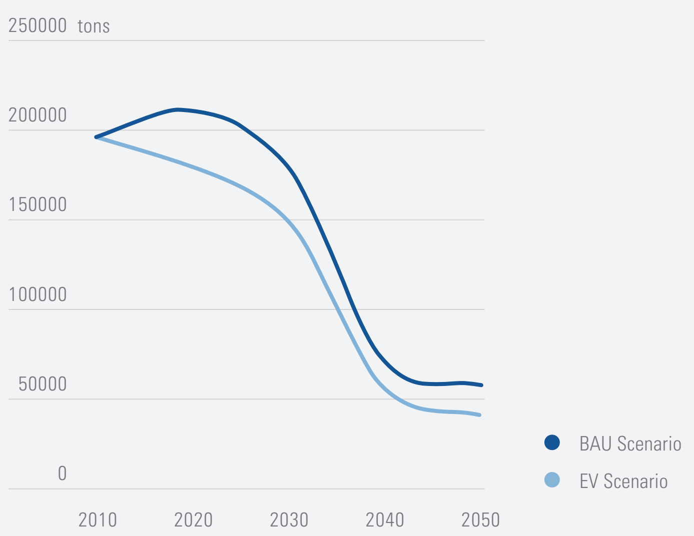


Figure 42. PM2.5 Emissions in BAU and EV scenarios



al., 2014), which can help in complementing this strategy. The Ministry of New and Renewable Energy (MNRE) has, as part of the Alternative Fuel for Surface Transportation programme, promoted research, development and demonstration projects on electric vehicles.

7.5 Technology, financing and R&D

The market share of EVs in India is still insignificant. Trends of EV sales show a higher market penetration of E2Ws compared to electric cars. This is indicative of a future trend where E2Ws will penetrate much faster in the country. This trend is also similar to that experienced in China during the past decade. Facilitating the large-scale penetration of EVs will require support from the national and city governments.

At the national level, fiscal concessions, e .g. sales tax, excise and customs duties will help to reduce the price of EVs and increase their competitiveness vis-à-vis conventional vehicles. National governments can enable domestic manufacturing through policies and incentives for manufacturers. Areas that require R&D funding are in battery technology, vehicle technology, charging infrastructures, distribution centres for charged batteries, recycling and reuse of batteries, and smart grids. Local governments can support EV penetration by providing infrastructure, integrating EVs in urban plans, EVs for public transport, and providing incentives such as free parking or EV priority lanes.

Photo Credit: Chase Ballew

8 Biofuels

Traditionally biomass fuels have been major sources of energy for rural populations in India. Recently, concerns over energy security and climate change have pushed biofuels as an effective response. Biofuels also offer multiple co-benefits vis-à-vis environmental, energy access, employment and local economic development.

India is a large producer of ethanol made from sugarcane molasses; however, around 61 per cent of this output goes to the potable (i.e. an alcoholic beverage) industry, and other applications (Purohit & Dhar, 2015). The surplus ethanol is being used for blending with transportation fuel since the Government of India (GoI) mandated 5 per cent blending of ethanol in petrol in 20 States and 8 Union Territories. However, the available surplus was not sufficient to achieve the 5 per cent blending target. In 2009, to strengthen its commitment to promoting biofuels, India adopted a National Policy on Biofuels. The policy encourages the use of biofuels as an alternative to petroleum products, and has also increased the target for blending of biofuels to 20 per cent (for both ethanol and biodiesel) by the end of 2017 (MNRE, 2009).

The government has put a 20 per cent blending target for biodiesel in diesel, and the preferred route is to extract biodiesel from Jatropha seeds. The achievement so far has been almost negligible. While the biodiesel plants produce 140-300 million litres of biodiesel annually, this is mostly consumed by the informal sector for irrigation and electricity generation, and by the automobile and transportation companies to run their experimental projects (USDA, 2015), with hardly any biodiesel being blended into diesel. The Jatropha program has not achieved the intended result due to low yields of Jatropha seeds, and therefore low incomes for farmers despite the Minimum Purchase Price. In 2015, the government has introduced a few initiatives that may help to improve the attractiveness of Jatropha, e.g. allowing biodiesel producers to directly sell to dealers and allowing freedom for pricing biodiesel.

8.1 BAU vs biofuels scenario

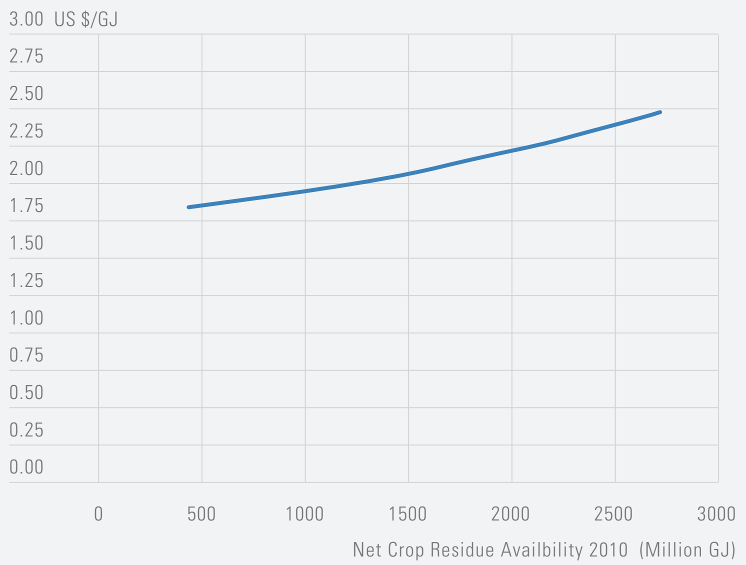
Blending of gasoline

Despite the government's increasing ambitions and its inclusion of most of the States, the achievement in blended gasoline has been low – it is available only in 13 states of India and the average blend is 2 per cent (GoI, 2014a). The oil companies that are supposed to blend cite shortage in supply of ethanol, whereas the Indian Sugar Mills Association (ISMA) cites low prices for ethanol as the reason for lack of supply (Purohit and Dhar, 2015).

The BAU scenario assumes a continuation of government policies, and that the achievement of blending targets is not forced. It assumes that the diffusion of biofuel will happen through market mechanisms. In addition to the ethanol from the sugarcane molasses, there is also the possibility of making use of second-generation biofuel using crop residues. The technical potential for this is well beyond what is required for 20 per cent blending (Purohit and Dhar, 2015); however, the economic potential within the BAU scenario is based on the cost of delivering biomass residue to the biorefinery gate (Figure 43) and the cost and efficiency of the biorefineries.

The biofuel scenario assumes that the 20 per cent blending target for gasoline with ethanol by 2017 would be achieved by 2020, and thereafter a 20 per cent blending of gasoline with ethanol is continued. In order to make this happen, the biofuel scenario considers that the government would provide price supports as a short-term strategy, and invest into research and development and pilot projects for the long-term success of the second-generation biofuels.

Figure 43. Biomass supply curve at biorefinery gate



This is an aggregate supply curve for the top ten States in India.
The top ten States are drawn in terms of their cropping intensities

Source : Purohit and Dhar, 2015.

Table 9: Emission coefficients of fossil fuels and biofuels

Fuel	Emission Coefficient Kg CO_2/GJ	% Reduction from fossil displaced	Reference
HSD	74.1	NA	IPCC, 2006
Gasoline	64.3	NA	IPCC, 2006
Ethanol - Sugar Beet	39.9	38%	Larson, 2006
Ethanol - Wheat Straw	12.7	80%	Larson, 2006
Biodiesel - Rape Methyl Ester	40.7	45%	Larson, 2006

Blending of biodiesel

In the BAU scenario, we assume the continued focus of government on Jatropha for their biodiesel program. However, by 2030, a 20 per cent blending of biodiesel would require around 40Mha of land (Purohit & Dhar, 2015). But since the total wasteland available is only around 12Mha (MoA, 2012), and the productivity of seeds on wastelands is low, the amount of biodiesel that could be produced using Jatropha was limited to 4 per cent required blending.

In addition to the biodiesel from the Jatropha, there is also the possibility of making use of the second-generation pathway using crop residues. As mentioned above with blending gasoline, the technical potential for this in the blending biodiesel is well beyond what is required for 20 per cent blending (Purohit and Dhar, 2015). However, the economic potential within the BAU is based on the cost of delivering biomass residue to the biorefinery gate (Figure 43), and the cost and efficiency of the bio-refineries.

In the biofuel scenario, the 20 per cent blending target for biodiesel is achieved not by 2017 as envisaged in NBP, but by 2030, keeping in mind that achievement using Jatropha is not good (Purohit & Dhar, 2015).

8.2 CO_2 reduction

The biofuel production process results in CO_2 emissions; however, in general biofuels are less CO_2-intensive than fossil fuels (Table 9). The reduction potential from biofuels however depends on the production pathway and the crops, the cropping intensity of bio-crops or bio-wastes, and the conversion processes that are used (Larson, 2006).

In the biofuel scenario, additional biofuels are helpful in reducing overall CO_2 emissions

(Figure 44). The cumulative reduction for the period 2010-2050 is 1,909 million tCO_2, and the emission level in 2050 is 11 per cent below the BAU level. The emissions reduction from a shift to biofuels is limited in the initial years because CO_2 reduction from biofuels are lower due to a greater role of first-generation pathways; however, as more biofuels are produced using crop waste the reduction potential of biofuels increases.

8.3 Co-benefits

Energy security

Biofuel blending would not bring down the overall demand for energy; however, it would be helpful in improving the energy security by: i) improving the diversity of supply; and ii) reducing dependence on imports. The reduced demand for oil will be 26MTOE in 2030, which would further increase to 35MTOE by 2050 (Figure 45).

Employment

Biofuels production can help to stimulate economic development and create jobs, especially in rural areas. These jobs would be across a wide number of sectors such as agriculture, construction, transportation, logistics, bio-refining and manufacturing. A large number of jobs would be in the rural areas, which have been left out of the development story, e.g. jobs in the biomass supply chain like collection and transportation of residues. It is expected that around 200,000 jobs would be generated to meet the 20 per cent blending target proposed in the National Biofuel Policy (Purohit & Dhar, 2015).

Biofuels are emerging as a leading means of diversifying the energy mix, improving energy security and delivering mitigation benefits. India has significant potential to scale up biofuel production and penetration, and this can be realized by addressing issues related to the supply of biomass and costs and investments in R&D for second-generation biofuels.

Figure 44. CO_2 Emissions Reduction by Sources – Biofuels Scenario

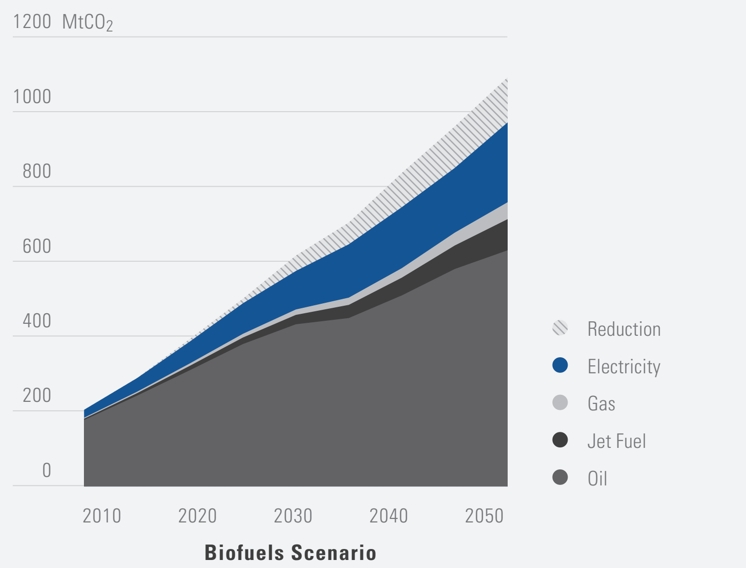
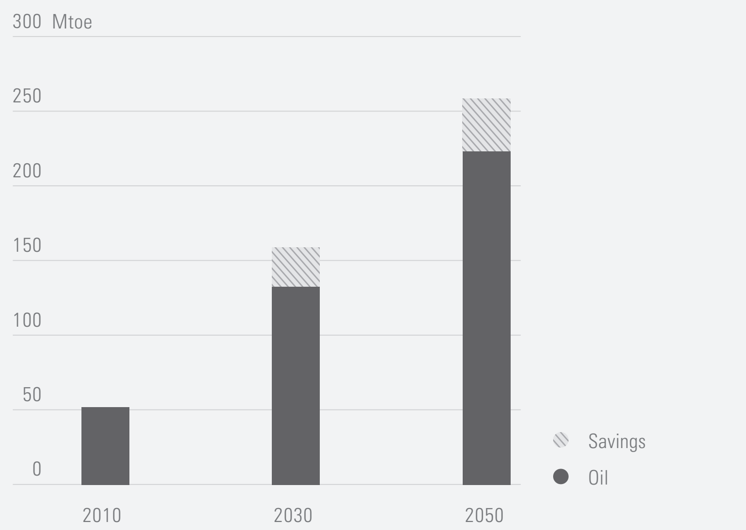


Figure 45. Oil Demand and Savings from Biofuels



Increasing the share of biofuels can improve energy access, generate jobs in rural areas, and facilitate balanced and sustainable economic development.

8.4 *Technology, financing and R&D*

Issues of supply and costs are major barriers to biofuel penetration. In the short run, the government can provide price supports as a short-term strategy. Similarly, new infrastructure investments can be aligned with the growing bio-energy supply chain and logistics. Public private partnerships, carbon market instruments, etc., can be leveraged to support biofuel penetration. R&D support for biofuels can involve research on alternate feedstocks, exploring non-agriculture feedstock like algae and production techniques (which can bypass intermediate bio-energy conversion stages, e.g. bio-hydrogen), and demonstration projects for second-generation biofuels,

Photo credit: FAO Aquaculture Photo Library

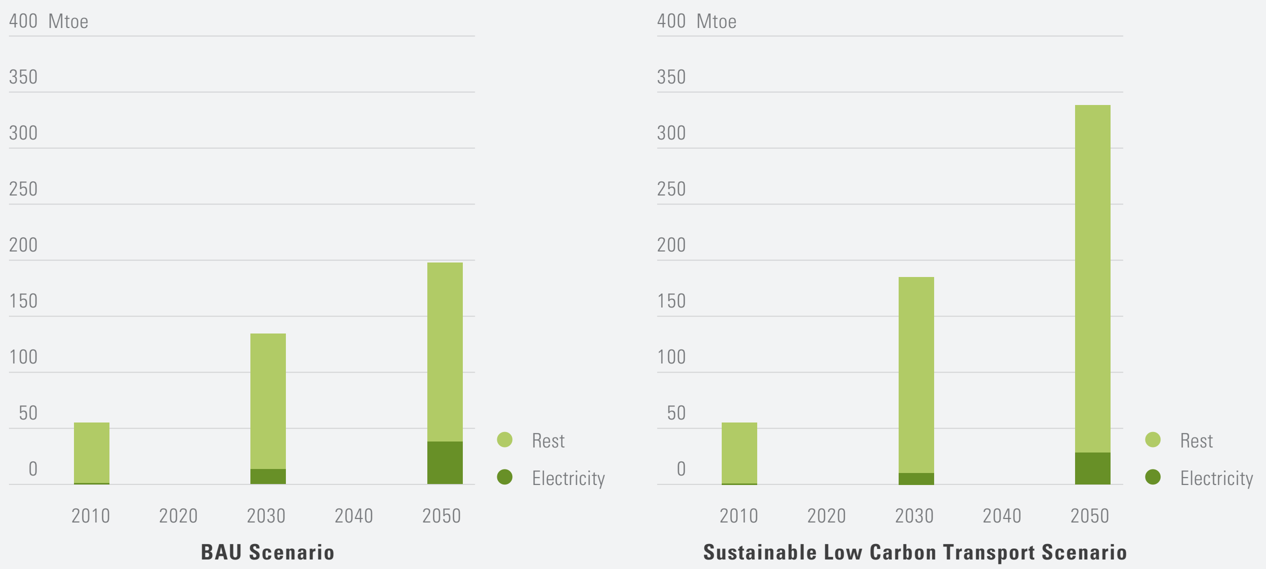
9 Electricity Cleaning

9.1 BAU vs sustainable low-carbon scenario

So far we have analysed the following sustainability strategies for transport: i) sustainable mobility for passenger transport; ii) sustainable logistics for freight; iii) vehicle fuel economy; iv) electric mobility; and v) biofuels. All these strategies are found to result in reductions of CO_2 emissions. Some of these alternative strategies would also lead to a change in fuel mix, and an increase in the share of electricity use. In the CO_2 reductions presented so far, the CO_2 intensity of electricity was considered similar in the BAU and alternative scenarios.

However, when the alternative storylines are combined for a sustainable low-carbon transport (SLCT) scenario, the climate regimes are considered to be different. In the case of BAU, the CO_2 emissions are pegged to a global stabilization target of 3.6°C, whereas under the SLCT the target is 2°C. The 2°C target has been agreed by all countries. The 2°C scenario requires strong climate policies that can limit the CO_2 emissions, and accordingly the CO_2 price trajectory for the SLCT is assumed to follow a path that is aligned with more ambitious Copenhagen pledges that come into force post-2020. The CO_2 price trajectory starts at a low level of US$13.9 per tCO_2 in 2020, and

Figure 46. Energy Mix between BAU and Sustainable Low Carbon Transport Scenario

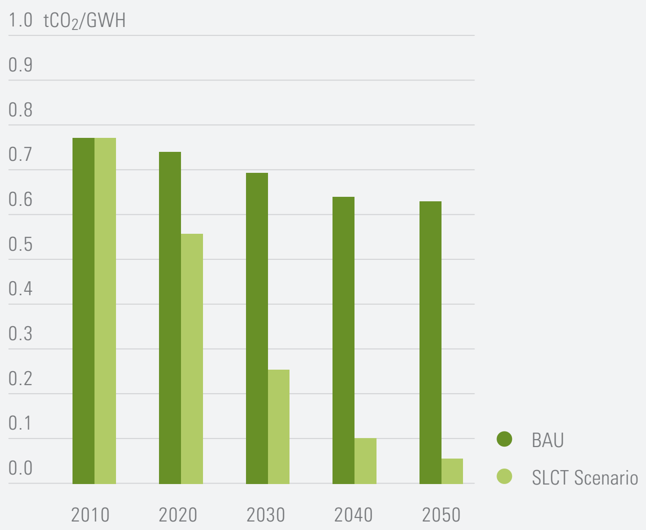


increases steadily to reach US$200 per tCO_2 by 2045 (Lucas et al., 2013).

9.2 *Energy transitions*

Electricity in transport is restricted to intercity rail and urban rail systems, as penetration of electric vehicles is currently very low. The overall demand for energy is much lower and future fuel mix will diversify further towards bio-fuels and electricity when we consider all the alternative strategies together in the SLCT. The transitions will be even faster when there is a high carbon price. Electricity is expected to play an increasing role in the future of transport in both the BAU and SLCT scenarios (Figure 46). The demand for electricity would come from strategies for sustainable passenger and freight transportation, e.g. due to the introduction of metro rail, other rail transit systems within cities, diffusion of high speed rail and dedicated freight corridors.

Figure 47. CO_2 Intensity of electricity



Source : Authors using results from ANSWER MARKAL model

Electric mobility would lead to an increased use of electricity within road transport and a wider diffusion of electric vehicles (including two-wheelers, cars and buses).

9.3 *Electricity CO_2 intensity: BAU vs sustainable low-carbon scenario*

Electricity generation in India is highly reliant on coal, and the government continues to see coal as the mainstay of power generation. Therefore the CO_2 intensity of electricity would decline due to efficiency improvements, but will remain high in BAU (Figure 47). In the sustainable low-carbon scenario, a strong climate regime, e.g. aligned to the 2°C target, can result in the decarbonization of electricity (Dhar et al., 2014; Shukla et al., 2015a), as renewables will be expected to play a greater role. The coal-based power generation occurs, however, in combination with carbon capture storage (CCS). Since electricity use is increasing within the transport sector, the decarbonization of electricity can result in the reduction of CO_2 emissions from transport.

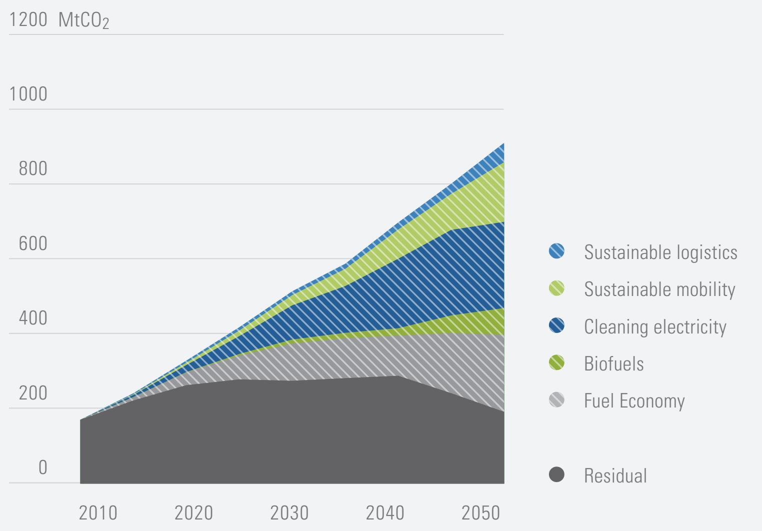
The decarbonization of electricity is limited early in the time horizon, but is reduced faster post-2025, and generates only 0.17 million tCO_2 per GWh in 2035. The decarbonization of electricity is achieved through a major shift in the electricity sector away from coal and deployment of CCS.

Progress with renewables in the Indian electricity sector will have far-reaching implications on transport. For example, several initiatives such as the Jawaharlal Nehru National Solar Mission (JNNSM) have been launched to improve the share of renewables in the generation mix. A roadmap for transition to smart grids has also been drawn. These changes hold the potential to both decarbonize the electricity sector and help in load management in the Indian electricity system.

9.4 CO_2 reduction

Electricity cleaning, in combination with all the alternative strategies on the demand side (for passenger and freight transport), plus supply side strategies (fuel efficiency, biofuels and electric mobility), can deliver the largest amount of reductions in CO_2 emissions (Figure 48).

Figure 48. CO_2 Mitigation wedges from transport



Source : Dhar & Shukla, 2015

10 Conclusions and Integrated Low Carbon Transport Roadmap

Transport policies and concomitant choices have wide ranging socio-economic and environmental implications that manifest across entire spatial and temporal scales. The assessment of transport policies hence keeps in view immediate to long-term (temporal) contexts and local to global (spatial) scales. In recent years, the framing of 'sustainable low carbon transport' has brought to the fore the rational and urgency to delineate integrated transport plan that simultaneously deliver wide ranging sustainable development goals including climate change mitigation and adaptation goals.

Transport sector is the second largest emitter after industry (Shukla et al., 2015a) and mitigating CO_2

emissions from the transport sector for mitigation efforts. In support of the global effort for achieving 2°C temperature stabilization target, the government of India recently submitted its Intended Nationally Determined Contribution (INDC) to the UNFCCC. The INDC positions the country as an active and constructive participant to contribute to the global challenge while simultaneously staying committed to the national sustainable development agenda. A key mitigation area outlined in the INDC is to develop a 'Safe, Smart and Sustainable Green Transportation Network'. A combination of measures to achieve these include increasing the share of railways in land transportation from 33% to 45%, improve energy efficiency of locomotives, urban mass transit projects, water based transport, road network to connect coastal areas and green highways are strategies outlined therein.

The national level assessment of low carbon transport in India spans a time horizon till 2050 and analyses two alternative scenarios using an economy-wide energy system model. The BAU scenario assumes continuation of existing policies and the absence of a national mitigation commitment. The BAU scenario therefore continues to remain highly dependent on oil, despite a small increase in share of electricity and alternate fuels. Energy efficiency and fuel emission norms bring about some benefits; however these are outpaced by the increasing demand for transport services. The low carbon scenarios follow the sustainable framework covering the full range of options belonging to the 'avoid-shift-improve' paradigm. The alternative sustainable low carbon transport strategies cover low carbon fuel-mix, decarbonisation of electricity, enhancement of infrastructure options for public transport and circumventing 'infrastructure lock-ins' into high energy paths, policies influencing behavioural changes and seizing opportunities to gain co-benefits such as from improved air quality and energy security indices,

Our integrated assessment shows that low carbon transport sustainable transition is possible for India. The five key wedges that deliver mitigation benefits in the SLCT scenario consistent with the global 2 ° C target are shown in Figure 48.

1. The highest mitigation is delivered through electricity cleaning which includes the uptake of EVs and decarbonisation of electricity. The carbon price in the Sustainable scenario facilitates higher share of renewables, natural gas and coal with CCS as a result of which the CO_2 content of electricity drops from 0.06 Million Tonnes (MT) CO_2 per GWH of electricity.
2. The second largest CO_2 reduction comes from advanced implementation of stringent fuel economy targets consistent with the vision

set under the Global Fuel Economy Initiative of achieving an average fuel economy of 4 l per 100 km in 2030

3. The third wedge is sustainable mobility spanning initiatives for passenger transport including faster implementation of Metros and BRT systems along with a better integration with non-motorised transport modes and feeder buses and higher share of rail in intercity transport.
4. The next wedge is from biofuel penetration which is facilitated through national policies and enabling mechanisms as well as carbon price
5. v. The fifth most significant impact comes from interventions in the freight transport sector which includes implementation of dedicated freight corridors, demand reduction for coal freight, etc.

Setting up the transport infrastructure in the country to meet the growing demand for passenger and freight transport while simultaneously addressing the challenges of environmental impacts at the local and global scales, is a formidable challenge for India. Given the stage of development, India has the opportunity of following a low carbon sustainable transport transition that can deliver substantial global mitigation benefits and can set an example for a number of other developing countries. This transition requires an integrated national low carbon transport strategy that plans for current and future services (passenger and freight), includes elements of systemic integration, infrastructure investments to improve connectivity and access at the local, regional and national level, while at the same time minimizing the energy and carbon intensity. This is possible and demonstrated in earlier sections in this report.

The following sections give a roadmap of key interventions to facilitate the transport transition towards low carbon green growth in India.

10.1 Low carbon urban mobility

India's urbanization rate at 32% is relatively low; however this will increase to 50% by mid-century. Urban transport policies therefore will have a significant influence in transportation demand and consequently energy use and emissions. In the Business-as-usual scenario, urban transport will continue to follow the current trend of dependence on private motorized modes despite the investments in public transport systems. Urban areas will continue to register higher increase in demand for cars and two-wheelers in the near term, however, in future, the difference in vehicle ownership between urban and rural areas will level out. Our modelling assessments show that the following strategies can deliver significant benefits for CO_2 reduction and co-benefits in the form of reduced air pollutant emissions, improved access and improved energy security.

Integrated Land Use Planning

Density and land use in a city influences the transport demand and mode choices. In the business as usual scenario, increase in urban sprawl increases and dependence on private transport modes. Vehicle efficiencies will improve, however these will get offset by the growth in demand for transport due to increase in population and urban sprawl.

The sustainable mobility scenario therefore includes development and implementation of an integrated urban transport strategy that aligns transportation and land use through tools and policies that reduce trip lengths and promote sustainable transport behaviour. These include measures aimed at promoting compact urban development, mixed land use that locates residences, amenities and commercial areas, increasing facilities for public transport and NMT, increasing density along transport corridors, use of traffic demand management, ICT. These should be integrated into a comprehensive low carbon mobility[1] plan that delineates actions to be implemented in the short, medium and long-term and mainstreamed into the overall urban development plan.

Public Transport, Non-motorized Transport and Supportive Policies in cities

Results from our assessment point to the fact that urban policies and investments in public transport including mass transit systems will underpin the transition to low carbon transport in India. Investments in mass transit will therefore be crucial to cater to the expected large transport demand in cities. These infrastructures can be funded from national government funds or exploring innovative mechanisms for raising local resources. Emerging climate finance instruments can also help support such investments.

Investments in public transport infrastructure however need to be supplemented with measures to facilitate access to public transport and make it more inclusive (Goel & Tiwari, 2014; Mahadevia et. al., 2013). Increasing frequency of buses, ensuring reliable service, increasing safety and comfort and intermodal integration will increase attractiveness of public transport. These could include integration with NMT, bike sharing schemes, and demand management measures such as parking charges, vehicle registration tax, etc. If complemented with public transport infrastructure, NMT infrastructure improvements in cities can make substantial contribution to improving access to public transport and consequently ridership.

NMT infrastructure and policies therefore should be an integral part of urban development plans. Increasing pedestrian and cyclists' Right of Way should be an important consideration in road widening and planning projects in cities. Since NMT infrastructures involve relatively small, investment it is also useful if they can be bundled with larger projects.

10.2 Advancing penetration of low carbon fuels and vehicles

The rising share of road-based passenger as well as freight transport and simultaneous decline in share of rail has been key driver of increasing oil use in transport. An important message from scenarios assessment is that despite the emergence of clean technologies (e.g. electric vehicles), conventional oil-dependent vehicles will dominate in BAU. Results also show that sustainability measures reduce the transport energy demand; however achieving the desired level of mitigation would require much higher penetration of alternate fuels and vehicles.

Electric vehicles

The substantial uptake and adoption of electric vehicles depends on global technological advances, awareness of citizens and support from national and local governments. In the long run, global influences, for instance the carbon price will facilitate low carbon electricity and increase the demand for electric vehicles. However, national government efforts, especially in the short and medium term are critical for early penetration.

Since the share of two-wheelers is already significantly high in India, it is possible to bring E2Ws faster compared to E4Ws. Earlier E2Ws penetration can help advance setting up of charging infrastructure and bring in early benefits of air quality improvements.

National enabling mechanisms will include setting the appropriate policy framework for EV manufacturers and allied industries, institutional

4 LCMP for Vizag, Rajkot and Udaipur can be download from http://www.unep.org/transport/lowcarbon/publications.asp

support to fund development and deployment of EVs, setting up standards and regulations for charging infrastructures (devices and batteries), financial incentives including subsidies for vehicles, investment into grids and charging infrastructures of batteries.

Local governments can facilitate EVs by a range of interventions including mandates and incentives that promote investments in charging infrastructure, developing local EV targets, stricter emission standards for vehicles, mandating alternate vehicles in city transport fleets, priority in parking and traffic for EVs, and facilitating public private partnerships.

Biofuels

The scenario assessment reveals that biofuels are important technology pathway for reducing oil dependence. The National Bio-fuel Policy, 2009 proposes a range of interventions to enhance the share of biofuels in the transport sector. In case of ethanol, the current policy aims at demand-side pull through mandatory ethanol blend with gasoline. For bio-diesel, the policies target the push along the entire supply-chain, beginning from land-use and feed-stocks (e.g. Jatropha, a crop suitable for arid land), process R&D and pilot plants (e.g. transesterification units) and supply to niche markets (e.g. buses and railway).

The biofuel scenarios are considering a 20% blending target of biofuels in gasoline and diesel and achievement of this is only feasible using second generation biofuels. The policy roadmap should therefore provide policy certainty for second generation biofuels. Since there is no experience in the technology demonstration projects and R&D are equally important. Biofuels using the second generation pathway are less CO_2 intensive and therefore a social value of carbon for valuation of biofuel projects is also recommended. A more detailed roadmap for biofuels can be obtained from Purohit & Dhar, 2015.

10.3 Increasing the share of rail in intercity passenger transport

In BAU scenario, the shift away from rail to air in long distances and to road for medium to short trips is expected. These trends are adverse for GHG emissions and national energy security since rail's energy and emissions performance is superior to air and road transport. The analysis shows that HSR and an overall improvement in rail services can overcome this adverse trend. In addition, compared to air, HSR can connect a number of small and medium cities and deliver a more balanced development. Rail can change the energy mix from oil to electricity, resulting in energy security benefits. HSR corridors, therefore, should form an important component of the national mobility plans. National governments should identify new high speed rail corridors. In addition, existing corridors should be identified for operating medium and semi-high trains.

HSR are however very capital intensive and should be proceeded by thorough assessment of not the project alone but an integrated national plan looking at all modes comprehensively will help understand demand and ridership for these modes and help prioritize investments. Regional rail and bus services can act as feeder systems for HSR to increase the catchment of the HSR infrastructure and benefit a large regional population. High Speed Rail can complement air modes by planning HSR infrastructure and time schedules strategically to align HSR with international airports.

10.4 Sustainable logistics

Dedicated Freight Corridors

Freight transport is a small but growing share of the overall energy demand from the transport sector. Recent initiatives including DFCs will bring about energy and CO_2 savings and will enhance regional connectivity, a critical input to deliver regional economic benefits. A strong case for replication of freight corridors is the additional dimension of sustainability from simultaneous environmental and development benefits for the country.

In order to optimize benefits from the planned dedicated freight corridors, investments in support infrastructures including freight terminals, special wagons, stack containers etc. will need to be facilitated as part of a comprehensive freight transport plan. The DMIC, a special industrial corridor coming up near the western DFC should be planned with integrated infrastructures including multi-Modal Logistics Parks and freight terminals at suitable locations.

Water based transport

Inland water based transport and coastal shipping are highlighted as important focus areas in India's INDC. There are existing plans to enhance the inland waterways transport, to establish integrated Waterways Transportation Grid connecting all existing and proposed National waterways with road, rail and ports connectivity. Another initiative in this direction is the Sagarmala Project with the objective to augment port-led development and promote efficient transportation of goods. Identifying important navigation routes, developing new infrastructure and strengthening allied infrastructure should be a part of an integrated water transport plan.

10.5 Financing through the Private Sector

Transport projects are capital intensive and often it is neither feasible nor desirable to fund these entirely through public finances. The national government can create an environment for private sector investments through an appropriate policy mix and incentives for sustainable transport policies. Innovative mechanisms that facilitate private sector participation are possible. Emerging areas that show potential for private sector participation are bio-refineries, bio-fuel retailing, HSR corridors, and EV infrastructure. Given that upfront investments are high in many of these projects and the benefits occur in a longer timeframe, financial instruments with long-term maturity should be considered.

10.6 Enabling domestic manufacturing

India will be a large market for low carbon businesses including low carbon technologies, infrastructures and services. The potential of several emerging transport infrastructures and systems offer significant opportunities for Indian manufacturers to become global players in emerging areas.

Given the established auto manufacturing industry in India, the expected growth in transport demand, and the recent interest in electric vehicles, India has the opportunity of creating domestic EV industry and emerging as a global leader in EV manufacturing market. Similarly, domestic manufacturing of rail and its components can promote innovation, opportunities for technology transfer and demand for industry – in particular, steel industry from manufacture of wagons and allied infrastructure. National industry policies can highlight this and make efforts to build domestic manufacturing capabilities. Strong and clear policy framework will give the right signal to industries, reduce investors risk and facilitate investments in these emerging areas.

10.7 Leveraging Climate Finance

Transport infrastructures need substantial upfront investments that offer investors long-term benefits, though their external co-benefits are immediate and substantial. National and city governments can leverage climate finance instruments to fast-track the implementation of these projects. There exists significant potential for developing bankable projects through CDM funds, NAMAs and Green Climate Fund for low-carbon mass transit projects, new vehicle technologies, and climate-resilient transport infrastructures. For instance, EVs, especially for para-transit and public transport can be recognised as a National Appropriate Mitigation Action (NAMA) due to their positive contributions for energy security, local environment, industrial development, renewable integration and CO_2 mitigation.

10.8 Improving connectivity of rural areas

Rural areas in India face challenges of accessing transport infrastructure and depend on inefficient transportation systems. This restricts their access to markets and employment opportunities. Development of roads and connectivity through rail to rural areas is therefore important to enhance mobility for rural areas.

10.9 Technology priorities and diffusion

There are multiple technology pathways for transiting to a low carbon transport however the portfolio of technologies and strategies that emerges from the model based assessment includes i) integrated urban and transport planning ii) improved public transportation and NMT within cities iii) dedicated freight corridors iv) improved rail and high speed rail v) second generation biofuels vi) electric vehicles and vii) more efficient cars and two wheelers. Each of these technologies would need an enabling policy framework and policy certainty and access to technology and financing.

Research & Development

Research and development (R&D) would be essential for second generation biofuels, electric vehicles, high speed rail, more efficient vehicles for a faster deployment and penetration by increasing their cost-effectiveness. For example, support for research on innovative models for battery and vehicle technology for EVs, improving availability of charged batteries, recycling and reuse of batteries, renewable integration, efficient pricing of electricity. The R & D efforts would however need to build both domestic capabilities and participation in global co-operation.

Technology Transfer and Financing

Indian INDC makes its contributions for mitigation contingent on access to technology and financing. India has advocated global collaboration in Research & Development (R&D), particularly in clean technologies and enabling their transfer, free of Intellectual Property Rights (IPR) costs, to developing countries. Since India would be a large market for EVs, bio fuels, etc. a stable policy environment and improved business environment would create an enabling environment for knowledge creation, design for innovation and development. However government would also need to invest in R&D labs as well as educational institution's so that a pool of trained and skilled manpower is created to cater to demand from both private sector and public institutions. In case of India the more important issue is of financing and the same has been discussed

10.10 Harmonizing Sustainable Development and Low Carbon Transport Actions

Analysis in this report shows that future evolution of India's transport system can harmonize the twin tracks of global policymaking - sustainable development and climate change. The report mapped variety of transport options for India using an integrated modelling framework. The analysis spanned different geographical scales (e.g. national subnational), diverse transport modes, variety of vehicles and fuels as well as financial constraints and the technological landscape.

Whereas transport policies are crafted generically at the national levels, the co-benefits are gained through coordination at sub-national hierarchies and balancing trade-offs at project levels. Cities are amongst the key subnational spaces where the benefits of sustainable low carbon transport accrue sizably and in the near-term. In case of India, the transition from low to high level of urbanization which is unfolding in the coming decades will sustain through the century. The demand for transport system thus will steadily rise through the century; thus offering opportunities to transform vehicle and infrastructure stocks. This is true for transport within the evolving cities as well as the intercity transport that link urban islands seeking mutually beneficial social and economic exchanges via passenger and freight movements.

Several ongoing programs present opportunities for low emissions development pathways. For instance, the government of India has recently announced a plan to allocate develop 100 smart cities in the country with an estimated investment of around USD 1.2 billion. The smart mobility actions for smart cities outlined by the Ministry of Urban Development include investments in public transport, non-motorized transport and other infrastructure which harmonise sustainability goals and low carbon targets. Bio-energy policy, EVs, HSR are similarly options that are low carbon and also sustainable,

In the overall, the report show the diversity and the richness of the universe encompassing policies, options, opportunities, constraints operating at different spatial and temporal scales that need to be represented to assess the sustainable low carbon transport policies and actions. The methodology of modelling assessment shows the necessity of integrating this diversity within a rational framework that delineates an integrated roadmap of distinct but interwoven options that deliver optimal results. The dynamic uncertainties shrouding an encompassing assessments needs adding the caution that such assessments need periodic updating; the guidance and insights they provide are often more important than the numbers.

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Appendix

Table a: Vehicle Ownership in Rural and Urban Households

Vehicle	% Households owning	
	2001	2011
Cycles (Rural)	42.80%	46.2%
Cycles (Urban)	46%	41.90%
Cycles (Overall)	43.70%	44.80%
	43.9%	44.8%
Two wheelers (Rural)	6.7%	14.30%
Two wheelers (Urban)	24.70%	35.20%
Two wheelers (Overall)	11.70%	21.00%
4 wheelers (Rural)	1.30%	2.30%
4 wheelers (Urban)	5.60%	9.70%
4 wheelers (Overall)	2.50%	4.70%

Table b: Definition used for structure of economy

Definition Used	National Account Statistics
Agriculture	Agriculture, forestry and fishing
Industrial	Manufacturing, mining and quarrying, electricity, gas and water supply, construction, storage, communication
Commercial	Trade, hotels and restaurants, financing, insurance, real estate, business services, public administration & defence and other services
Transport	Railways & transport by other means

Table c: Intercity passenger demand (Bpkm)

Year	Rail	Air	Road
1985	240.6	16.0	850.0
1986	256.5	16.9	893.0
1987	269.4	18.1	980.0
1988	263.7	18.6	905.0
1989	280.8	18.3	1281.6
1990	295.6	15.9	1257.4
1991	314.6	16.2	1320.5
1992	300.0	16.5	1343.0
1993	296.0	17.4	1432.1
1994	319.4	19.5	1500.0
1995	341.9	22.5	1550.0
1996	357.0	22.7	1724.0
1997	380.0	23.3	1863.2
1998	403.9	24.1	1860.4
1999	430.7	24.6	1831.6
2000	457	26.2	2075.5
2001	490.9	25.0	2413.1
2002	515	28.7	2814.7
2003	541	32.7	3070.2
2004	576.0	40.3	3469.3
2005	616.0	51.6	4251.7
2006	695.0	33.5	4545.8
2007	770.0	77.8	4860.3
2008	838.0	78.4	5196.5
2009	903.4	89.4	5555.9
2010	978.5	103.2	5940.3
2011	1046.0	112.8	6351.2

Table d: Freight Demand (Bpkms)

year	Rail	Road	Air
1985	205.9	193.0	0.41
1986	223.1	210.0	0.42
1987	231.2	238.0	0.49
1988	230.1	275.0	0.49
1989	236.9	295.0	0.51
1990	242.7	289.3	0.45
1991	256.9	321.5	0.36
1992	258.0	339.0	0.32
1993	257.0	355.7	0.34
1994	253.0	350.0	0.42
1995	273.5	413.0	0.47
1996	280.0	449.4	0.44
1997	286.8	480.8	0.45
1998	284.3	483.4	0.46
1999	308.0	467.0	0.54
2000	315.5	494.0	0.55
2001	336.4	515.0	0.54
2002	356.0	545.0	0.57
2003	384.0	595.0	0.59
2004	411.3	646.0	0.74
2005	441.6	658.9	0.80
2006	481.0	766.2	0.86
2007	521.4	851.7	1.04
2008	551.5	920.2	1.20
2009	600.5	1015.1	1.43
2010	625.7	1128.5	1.65
2011	667.5	1212.4	1.75

Table e: Population transitions in 50 most populous cities

		2000	2010	2025	2050
1	Delhi	15732	21935	32935	43957
2	Mumbai	16367	19422	26557	33378
3	Kolkata	13058	14283	18711	22895
4	Bangalore	5567	8275	13193	18332
5	Chennai	6353	8523	12814	17147
6	Hyderabad	5445	7578	11647	15811
7	Ahmedabad	4427	6210	9599	13084
8	Pune	3655	4951	7487	10068
9	Surat	2699	4438	7530	10904
10	Jaipur	2259	3017	4557	6131
11	Kanpur	2641	2904	3910	4887
12	Lucknow	2221	2854	4234	5630
13	Nagpur	2089	2471	3498	4517
14	Indore	1597	2127	3233	4369
15	Coimbatore	1420	2095	3413	4824
16	Patna	1658	2022	2904	3786
17	Bhopal	1426	1851	2786	3743
18	Vadodara	1465	1794	2605	3422
19	Agra	1293	1714	2615	3545
20	Visakhapatnam	1309	1700	2570	3463
21	Ludhiana	1368	1598	2257	2912
22	Kochi	1340	1592	2285	2979
23	Nashik	1117	1531	2376	3257
24	Vijayawada	999	1453	2370	3354
25	Madurai	1187	1443	2110	2786
26	Varanasi	1199	1419	2036	2655
27	Meerut	1143	1406	2054	2710
28	Rajkot	974	1361	2145	2971
29	Jamshedpur	1081	1320	1924	2534
30	Srinagar	954	1251	1909	2591
31	Jabalpur	1100	1257	1763	2266
32	Asansol	1065	1232	1733	2232
33	Allahabad	1035	1205	1712	2219
34	Aurangabad	868	1167	1801	2462
35	Dhanbad	1046	1186	1655	2121
36	Amritsar	990	1171	1675	2180
37	Jodhpur	842	1116	1721	2350
38	Raipur	680	1088	1874	2750
39	Ranchi	844	1107	1689	2292
40	Gwalior	855	1084	1631	2193
41	Durg-Bhilainagar	905	1054	1496	1939
42	Chandigarh	791	1010	1517	2039
43	Tiruchirappalli	837	1009	1472	1942
44	Kota	692	978	1572	2207
45	Mysore	776	969	1447	1938
46	Bareilly	722	961	1494	2052
47	Tiruppur	523	927	1698	2591
48	Guwahati	797	957	1387	1822
49	Kozhikode	875	961	1328	1692
50	Thiruvananthapuram	885	952	1301	1646

Source: UN (2014) till 2025 for city wise breakup and 2050 projection based on overall urban projection available from UN (2014)

Table f: Passenger Transport Demand Projection (NTDPC)

	Rail (Elasticity = 1.1)	Road (Elasticity = 1.9)
2006	695	4657
2011	1047	9329
2016 (GDP=6.9%)	1,509	17,272
2021 (GDP = 8%)	2,301	35,043
2026 (GDP = 8.5%)	3,598	74,080
2031 (GDP = 9%)	5,768	163,111

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